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THE DESIGN OF LOGAIR FEEDER ROUTES

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LSSR 37-77A

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LOGAIR is the U.S. Air Force contracted commercial air carrier system which provides daily delivery of reparable and consummable items to all major USAF installations in the continental U.S. The system is completely airlift dedicated and does not consider other modes of transportation. This thesis develops and tests a method of minimizing LOGAIR feeder route transportation costs which allows for a general comparison of distribution options such as mixing transportation modes and varying performance levels. The mathematical model developed is a binary linear program which allows maximum flexibility for performing sensitivity analysis over a variety of constraint requirements. Example problems demonstrate the savings which may be realized by the introduction of surface vehicles and the relaxation of certain performance requirements.

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THE DESIGN OF LOGAIR FEEDER ROUTES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

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INTRODUCTION

Statement of the Problem

Air Force weapons systems receive their material support from five Air Logistics Centers (ALC) operated by the Air Force Logistics Command (AFLC). These ALCs are linked together and to major Continental United States (CONUS) installations through various contract, common carrier, and government transportation systems. The primary freight network, LOGAIR, is a contract air cargo system which will cost the Air Force 49.8 million dollars to operate in fiscal year 1977 alone (7).

The LOGAIR route structure consists of a primary (trunk) network which connects the ALCs to the Aerial Ports of Embarkation (APOEs) and several secondary (feeder) networks which connect the ALCs to the customer bases (18:A-2-A-4). The entire structure is presented in Figure 1. Daily service is provided to each of these customer bases via a feeder route which originates and terminates at an ALC.

Attempts to optimize the operation of this network over the past decade have resulted in only partial success due to the size and complexity of the overall system. The

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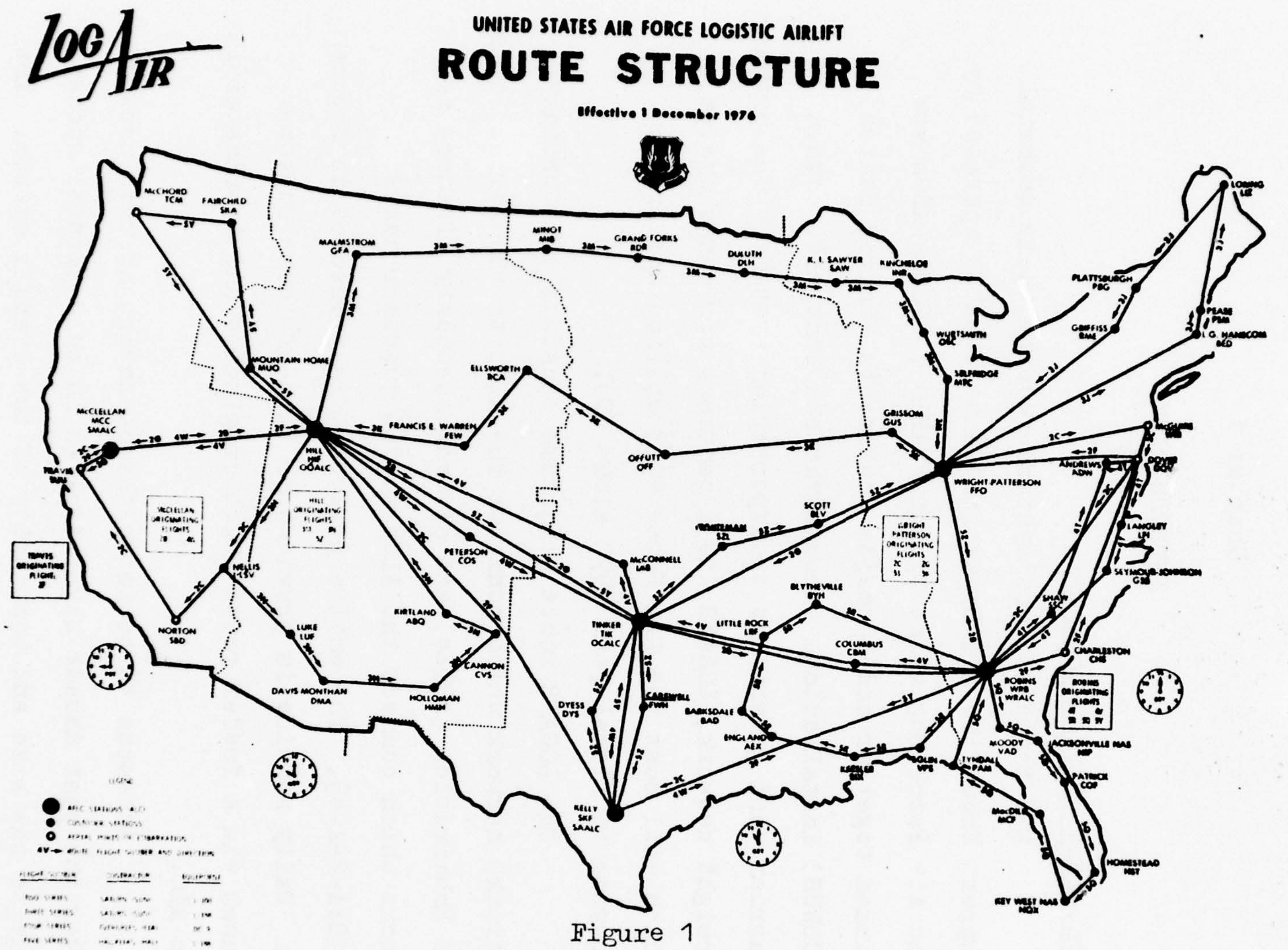

Figure 1

LOGAIR Route Structure

LOGAIR feeder route structure is developed by a manual process even though the primary trunk network has been significantly improved through time-saving computer assisted models (11:1). Since this manual process depends upon heuristics, the feeder route structures which are developed are not necessarily optimal[1] in terms of either effectiveness or efficiency and consequently the process is not conducive to sensitivity analysis.[2]

This thesis develops an optimizing method of determining LOGAIR feeder route structures that allows for a general comparison of distribution options such as mixing transportation modes and varying performance levels.

Background

LOGAIR is the U.S. Air Force contracted commercial air carrier system which provides daily delivery of reparable and consumable items to all major USAF installations in the CONUS. The system provides daily scheduled service among 60 stations including the ALCs, customer bases, and APOEs.

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[1]An optimal solution is a feasible solution that is the most favorable in terms of cost (8:32).

[2]Sensitivity analysis means to vary one or more parameters over some interval(s) to see when the optimal solution changes (8:193).

Air Force Manual 76-1, The LOGAIR Traffic Manual, lists the objectives of the system as follows:

1. Establish and maintain a cargo airlift service,

2. Improve the timeliness and effectiveness of logistical support by expanding and improving the utilization of air transportation, and

3. Improve the quality and reliability of the system (18:3-1).

The LOGAIR system supports the movement of all priority 1 and priority 2 cargo.[3] Priority 3 cargo may also be moved to the first downline station on a space available basis (18:4-1). The system is completely airlift dedicated and does not consider alternate modes of transportation.

Developing requirements for airlift. Each major Air Force installation submits a forecast of priority 1 and priority 2 tonnage based upon first quarter historical data supplied by AFLC. The LOGAIR Requirements Branch[4] then develops, from these data, a series of requirements matrices between

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[3]Transportation priority codes are determined from a matrix of Force/Activity Designator Codes versus Urgency of Need Codes. Resulting combinations are prioritized as transportation priorities 1, 2, and 3. (Source: DoD Directive 4410.6)

[4]LOGAIR Requirements Branch, HQ AFLC/LOTSL, Wright-Patterson AFB OH.

origin stations and destination stations. The matrices are then partitioned into trunk stations and feeder stations.[5] A route structure is then developed which considers the tonnage and type of aircraft necessary, delivery times, number of landings, and flight scheduling. The route structure is costed in accordance with Civil Aeronautics Board (CAB) rates and anticipated contract costs, and then sent to the Air Staff for review and approval (13:G-2).

Other attempts. Research efforts in this area have provided both relief and insight into the LOGAIR problem. Captain Michael F. McPherson and Captain Brian O'Hara, in a master's thesis presented to the Air Force Institute of Technology in June 1976, expanded upon a previous master's thesis (14) in developing a computer-assisted method for determining LOGAIR route structures. These studies only considered the trunk route structures in developing a mixed-integer programming model for minimizing costs. The McPherson and O'Hara model showed that successful reduction of LOGAIR contract costs was possible. However, even though only 12 trunk nodes were considered, the computer algorithm

[5] In general, a trunk station is one which processes approximately 2,000 tons or more of cargo per year. A feeder station processes less than 2,000 tons (7).

used could not generate an optimal solution within five hours unless the trunk route structure problem was divided into two sub-problems (11:25-27). This limitation highlights the enormity of the task of developing an overall optimizing solution. Due to present state-of-the-art and computer resource constraints, obtaining a total optimum solution for all feeder nodes in consonance with the trunk structure appears impossible.

A study conducted in 1976 for the Department of Defense by E. A. Narragon and J. M. Neil, Logistics Management Institute, contained two significant innovations: the study was (1) the first formal attempt to evaluate the savings possible by modifying the present feeder network structure, and (2) the first study to consider the time/cost trade-offs possible by utilizing a mixture of air and surface (truck) transportation. The Logistics Management Institute study pointed out, "There is an excellent surface transportation system within CONUS upon which LOGAIR managers are not capitalizing [13:G-4]." Considerable savings might be realized from an optimum mix of air and surface transportation which can maintain the required performance level.[6]

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[6]Performance level is measured with respect to time and consistency (1:28). The performance level required for priority 1 and priority 2 cargo is one day delivery (DoD Directive 4410.6).

Justification

Although lowest total cost expenditure was not an explicit objective of the LOGAIR charter circa 1969 (18:3-1), justification for reducing LOGAIR costs[7] has subsequently been documented (11:6). Soaring fuel costs and dwindling fuel reserves dictate that the system be constantly scrutinized for ways to increase the overall efficiency in terms of defense dollars. The fiscal year 1968 Department of Defense budget, which was being formulated at the same time the LOGAIR manual was being written, comprised 43.6 percent of the Federal Budget. In contrast, President Ford's fiscal year 1977 budget allocated only 25.4 percent to the military. The Air Force's share of the Department of Defense budget decreased from 33.0 percent to 27.7 percent in the same period (19:108).

Previous efforts to reduce distribution costs, with respect to LOGAIR, have been directed at the design of the trunk route structure in order to provide a more efficient solution by reducing the total air miles flown (11:7). No progress has been made in terms of viewing the overall savings possible if LOGAIR is viewed as a complete system itself.

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[7]The most recent cost figures show that the total contract cost, including fuel subsidies, for fiscal year 1976 was $46.4 million. The estimated cost for fiscal year 1977 (disallowing increased fuel costs) is $49.8 million (7).

The capability to analyze alternatives within the AFLC distribution system, including various mixes of air and land transportation, inventory costs versus pipeline times, transshipment points, etc., is necessary if the most cost effective system at any one time is to be identified.

The performance of the total distribution system (including LOGAIR) in terms of efficiency and effectiveness is singularly important. Components linked together as a system can produce an end result which is greater than that possible by individual performance. Consequently, all components must be evaluated on the basis of their contribution to the system, as opposed to individual performance.

> In final analysis it makes very little difference whether a firm spends more or less dollars for an individual component--warehousing for example--as long as the overall logistical objectives are achieved as the lowest total cost expenditure [1:17-18].

Objective

The objective of this research effort was to develop a computer model for minimizing LOGAIR feeder route contract costs. A secondary objective was to vary performance parameters in order to analyze trade-offs between cost and performance.

Chapter 2

MODEL DEVELOPMENT

General

The mathematical model developed for LOGAIR feeder routes is a binary linear program.[1] The model was designed to find a minimum cost route structure given a fixed number of bases and various performance constraints. The model structure allows maximum flexibility for performing sensitivity analysis over a variety of constraint requirements. The characteristics of the model are explained in detail as they apply to the model derivative, data inputs, and validation. The software package used to solve the problem is presented in RAND Report RM-5627-PR, and is also available on CREATE.[2]

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[1] A special linear programming problem whereby all the variables are restricted to two values: zero or one. A variable is used to indicate whether some possible action is to be undertaken (X=1) or not (X=0) (8:705).

[2] CREATE is an acronym for the GE/Honeywell 635 computer system at the Air Force Institute of Technology. CREATE stands for Computational Resources for Engineering and Simulation Training and Education.

Model Derivation

Previous research efforts have been conducted on the general vehicle dispatching problem first formulated by Dantzig and Ramser (2:309). The general problem is to satisfy the supply demands of a set of customers with known locations and requirements from a depot via vehicles of known capacity. The objective is to minimize costs of delivery subject to constraints of customer requirements, vehicle capacities, and either time or distance restrictions on the vehicle.

A mildly successful evaluation of the LOGAIR freight delivery system within the context of the vehicle dispatching problem was initiated as early as 1966.[3] Recent efforts to improve the LOGAIR system were the route structure model developed by Palmatier and Prescott (14), and the subsequent improved model by McPherson and O'Hara (11). Although these models considered essentially the same problem, the solution times required for sensitivity analyses could not be obtained from the branch and bound algorithm employed. The inefficiency of the branch and bound technique, when used with the vehicle scheduling problem, has previously been noted by Christofides and Eilon:

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[3] A combined heuristic and linear programming route generation technique was proposed by the RAND Corporation in October 1966 (5:4-11).

> Clearly the computational efficiency of the branch and bound algorithm when applied to the vehicle scheduling problem is substantially reduced when compared with its efficiency in solving an equivalent traveling salesman problem [2:316].

The inability of the McPherson and O'Hara model to reach an optimal solution for the 12 node trunk structure lends credence to this contention.

Several heuristic models were investigated, however, the improbability of obtaining consistent near-optimal solutions using heuristics eliminated such methodology from extensive consideration (2:316-318). Near optimal solutions would be necessary to conduct the desired sensitivity analysis on the performance parameters.

A model was developed by this research team which combined the features of optimality, simplicity, ease of application, and amenability to sensitivity analysis.

The Model

The problem, as was previously stated, is to minimize the contract costs of transporting cargo within a LOGAIR feeder system. The present feeder systems are completely airlift dedicated and do not consider other methods of shipment. The task of generating a minimum cost feeder route structure involves selectively choosing the cheapest method of transporting cargo between each base and its parent ALC, providing the selected mode can meet the

requirements of time and capacity. To determine the total minimum cost, consideration must be given to all possible routes among individual bases and between the individual bases and the ALC. Also, all possible modes of transportation on these routes must be considered. Since daily demands of cargo at each base are known and the cost of each mode of transportation can be determined, an objective function was, therefore, formulated to minimize the total transportation cost of a feeder route.

The objective function is subject to several constraints such as (1) delivery time, (2) minimum vehicle visits, (3) out and back requirements, (4) balance constraints, and (5) vehicle capacities.

Objective function. The decision variables of the model are defined to be binary variables indicating the options of traveling from one location (customer base) to another via a specified vehicle. A binary variable is equal to one if the corresponding route and vehicle is selected; otherwise, the variable is equal to zero. The sum of the cost coefficients of the non-zero variables in the objective function then determines the cost of that feeder route. The objective function is expressed mathematically as follows:

$$\text{Minimize:} \quad \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{m} C_{ijk} X_{ijk} \qquad i \neq j$$

Where C_{ijk} = cost to travel from base i to base j in vehicle k

and $X_{ijk} = \begin{cases} 1, \text{ if vehicle } k \text{ is used between base } i \text{ and base } j \\ 0, \text{ otherwise} \end{cases}$

i = departing base index

j = arriving base index

k = number of the vehicle placed in the system for consideration

<u>Constraints</u>. The first set of constraints are the delivery time constraints. These are included to allow comparisons among route costs for various maximum delivery time criteria. Time is specified in terms of hours, and the constraint indicates the maximum time allowable to deliver goods from the hub of the feeder network (the ALC) to all of the nodes (bases) in the network. That is, a vehicle may depart an ALC and visit one or more bases, but it must return to the ALC within a maximum specified time. Only those interbase routes whose decision variables are not zero are included in the summation. The general delivery time constraint is expressed mathematically as follows:

Constraint 1: $\sum_{i=1}^{n} \sum_{j=1}^{n} t_{ijk} X_{ijk} \leq T \quad k = 1, 2, 3, \ldots m$

Where t_{ijk} = the time in hours to travel from base i to base j in vehicle k

T = maximum time allowable for the sum of interbase segments

The second constraint insures that each base will be visited by exactly one vehicle since the sum of the set of decision variables for all vehicles on each route entering a base is set equal to one.[4] This means that all but one of the decision variables must equal zero, allowing only one vehicle on a particular route segment. It is assumed that one vehicle per day, either aircraft or truck, will be sufficient to satisfy the daily demand of any base. Constraint two is expressed as follows:

Constraint 2: $\sum_{i=1}^{n} \sum_{k=1}^{m} X_{ijk} = 1 \quad \text{for } j = 1, 2, 3, \ldots n \quad i \neq j$

The out and back constraint insures that the number of vehicles which depart the ALC will equal the number which return. The constraint is expressed mathematically as follows:

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[4]This constraint is partially relaxed at the ALC to allow all solution vehicles to return to the ALC.

Constraint 3: $$\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ijk} \leq M \sum_{i=1}^{n} X_{i1k}$$

$$\text{for } k = 1, 2, 3, \ldots m$$
$$i \neq j$$
$$\text{base } 1 = \text{ALC} \qquad M = \text{large number}$$

The out and back constraint for a vehicle "k" insures that if that vehicle is used anywhere in the feeder network it will be forced to return to the ALC. In conjunction with Constraint 4, this will also insure that each vehicle in the system departs the ALC. In essence, this constraint forces each vehicle out of the ALC and then back into the ALC.

The fourth set of constraints, the balance constraints, insure that a vehicle which enters a base also leaves that base. These constraints are written as follows:

Constraint 4: $$\sum_{i=1}^{n} X_{ijk} = \sum_{l=1}^{n} X_{jlk} \quad \text{for } k = 1, 2, 3, \ldots m; \; j = 1, 2, 3, \ldots n; \; i \neq j$$

If vehicle k travels from base i to base j, it must also travel from base j to base l. In other words, any vehicles entering base j also will leave base j.

The capacity constraints are similar to the time constraints in that they can provide a comparison of route structures controlled by vehicle weight and volume

limitations. These constraints will insure that the most restrictive of the two will contribute to the selection of the proper decision variables.

Constraint 5: $$\sum_{i=1}^{n} \sum_{j=1}^{n} W_j X_{ijk} \leq W_k \quad \text{for } k = 1, 2, 3, \ldots m, \quad i \neq j$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} V_j X_{ijk} \leq V_k$$

Where W_j, V_j = weight and volume inputs from the ALC to base j

W_k, V_k = weight and volume capacities, respectively of vehicle k

The weight and volume constraints provide that individual capacities of each interbase route-vehicle combination will be summed and compared to the maximum allowable vehicle capacity.

<u>Problem size</u>. Problems formulated with the basic model will have the following numbers of variables and constraints:

$$\text{Number of variables} = \binom{N}{2} \times 2 \times M \qquad (1)$$

$$\text{Number of constraints} = 4M + N + M\,(N-1) \qquad (2)$$

Where N = total number of bases in the network, and

M = total number of vehicles in the network.

As can be seen from these equations, the number of variables and constraints increases exponentially as the numbers of bases and vehicles increase.

The implicit enumeration algorithm which will be used to solve the problem, is dimensioned for 100 constraints and 150 variables. No further increase in dimension was possible because of the memory capacity limits of the computer system.

Data Collection

The LOGAIR feeder system data required were available at AFLC Headquarters and also within current Air Force publications. The data were categorized as follows: (1) customer demand, (2) vehicle capacity, (3) vehicle transit time, and (4) direct (vehicle) operating cost. Each of these categories are discussed here in relation to information sources, model data requirements, and data transformations.

Demand. Daily demands for every major Air Force base are available in the standard data base of the AFLC Control Data Corporation (CDC) 6400 CYBER computer.[5] The base demands represent the average daily tonnage and cubic feet

[5]The demand data were obtained from the DoD Material Distribution Systems Study Group (DODMDS), courtesy of AFLC/XRS (16).

requirements for the period 1 October 1974 through 30 September 1975. The demand data require no transformation, and are presented in Appendix C. Discussions with personnel at the AFLC Directorate of Transportation, LOGAIR and Requirements Branch (LOTSL) indicated that these demand figures can be considered accurate estimators of demand for route planning purposes (7;9).

Capacity. Various vehicle capacities by weight and volume are required for establishing the capacity constraints. Both weight and volume are included to insure that the most restrictive feature directly influences the optimal decision. Aircraft capacities were obtained from the LOGAIR FY 77 Flight Schedules and Routing Guide (17:ii-iv). Various truck capacities were obtained from the Chief Quality Control Inspector, Transportation Office, at Wright-Patterson AFB. Due to the wide variety of trucks employed nationwide, only standard capacity vehicles (i.e., the most common) were considered. Various vehicle capacities are tabulated in Appendix C.

Transit time. The travel time for any vehicle between any two feeder nodes is equal to the distance between the nodes times the estimated average speed of the vehicle plus the load and unload time. Air miles used are great circle

straight line distances (statute miles) obtained from current CAB directives (17). Surface miles were obtained from AFM 177-135, Official Table of Distances (20). Distance matrices for the air and surface miles and the average speeds and load and unload times for each vehicle type are shown in Appendix C.

Cost. The determination of costs to service feeder segments by different modes of transportation is different for aircraft and surface vehicles. Aircraft cost data were obtained from AFLC/LOTSL and include the basic plane cost per mile, fuel subsidy, adjustment for the carrier's net earnings tax and landing fees. The first three factors were transformed into a total per mile cost; this resultant per mile cost times air distance between feeders and the landing fee produces the cost per route segment per aircraft. The cost of service by various trucks can only be estimated from existing dedicated truck contracts and recent contractual history, as a standard rate does not exist. Each service contract is negotiated individually by the Military Traffic Management Command (MTMC) (9). Appendix C lists the costs per mile for both aircraft and trucks.

Model validity. Internal validation was a continuing process throughout all phases of the model development and testing.

The internal validity was enhanced by continual cross-checking of mathematical manipulations and tabulations for accuracy and correctness. Assumptions and logic flow were continually reviewed for appropriateness particularly in the development phase.

Three external validation phases were required to insure that the model worked properly and that the total software package was convenient to use. The first phase required that the pilot problem be manually formulated and put into the RIP30C program to insure that the problem could be solved. The second phase required the validation of the matrix-generative FORTRAN program which was written to facilitate the data input for the RIP30C program. The third and final external validation phase consisted of solving for an optimum solution for the present LOGAIR Route 5R and performing a sensitivity analysis. This phase of the model validation is covered in Chapter 4.

Sensitivity analysis. An extensive sensitivity analysis was conducted to complete the external validation and to demonstrate the flexibility of the model. Minimum cost route structures were determined for a variety of input conditions, generalized as follows:

1. Alternatives to the present policy of one-day delivery to each customer were explored.

2. Base demands were varied to include priority 3 big load, and priority 3 big and small load, cargo.

3. The type of vehicles were varied in an attempt to determine a relationship with size of demands.

Summary of Assumptions

1. The data obtained from AFLC Transportation Directorates are valid.

2. Demands are deterministic (known with certainty).

3. Time measures are linear (11:23).

4. More cargo goes into a base than comes out.

5. One vehicle per day, either aircraft or truck, will be sufficient to satisfy the daily demand of any base.

Chapter 3

PILOT STUDY

General

Although the basic model is bi-directional in nature, the problems considered here were formulated to permit travel in one direction only. The exception to this rule is that the arcs connecting the bases with the ALC permit travel in both directions. This exception is to permit a vehicle to visit any base in the system at either the start or the finish of a route, depending on the merits of the individual arrangements.

The one-way travel restriction has the advantage of reducing the number of variables[1] in the model and thereby permits a larger problem to be solved with the given computer limitations (time and core space). If each arc connecting two bases is allowed to have traffic flow in either direction,[2] then the total number of variables in the problem is computed by use of Equation 1.

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[1] The number of constraints is determined by the total number of nodes and vehicles, and is not affected by either flow selection.

[2] It is assumed that there is no difference in cost between traversing an individual arc in one direction vice another. The shortest connecting route between several

By contrast, the number of variables in the problem formulation, given the one-way restriction, is:

$$\text{Number of variables} = \left[\binom{N}{2} + (N-1)\right] \times M \qquad (3)$$

For comparison, Table 1 and 2 summarize the number of variables required for various combinations of nodes and vehicles for both one-way and two-way travel. The area below the heavy lines indicates the area where artifically imposed computer limitations would not permit complete problem solutions.

Pilot Problem

A logistics network which consisted of three customer bases, one ALC, and two vehicles was fabricated to assist in validating the model and developing the necessary software. The problem was constrained so as to permit a solution to be determined either by inspection or by an implicit enumeration algorithm. Of the three customer bases (nodes 2, 3, and 4), two of them (nodes 3 and 4) were located sufficiently close to the ALC (node 1) to permit access by surface transportation. The other base (node 2) was accessible by aircraft only because of the time

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nodes may be affected by the one-way restrictions however. The optimality of the solution in this case will depend upon the numbering system, as will be discussed later.

Table 1

Basic Variables

(One-Way Travel Model)

Number of Bases, N	Number of Vehicles, M				
	2	3	4	5	6
2	4	6	8	10	12
3	10	15	20	25	30
4	18	27	36	45	54
5	28	42	56	70	84
6	40	60	80	100	120
7	54	81	108	135	162
8	70	105	140	175	210
9	88	132	176	220	264
10	108	162	216	270	324
11	130	195	260	325	390
12	154	231	308	385	462

Table 2

Basic Variables

(Two-Way Travel Model)

Number of Bases, N	Number of Vehicles, M				
	2	3	4	5	6
2	4	6	8	10	12
3	12	18	24	30	36
4	24	36	48	60	72
5	40	60	80	100	120
6	60	90	120	150	180
7	84	126	168	210	252
8	112	168	224	280	336
9	144	216	288	360	442
10	180	270	360	450	540
11	220	330	440	550	660
12	264	396	528	660	792

constraint. For the sake of simplicity only two vehicles were considered in the problem--an aircraft and a truck. The values selected for the problem variables were similar to actual data.

Problem Solution

Manual solution. The optimum solution to the pilot problem is shown in Appendix B. It can be readily seen that there are only two feasible solutions to the problem because of the constraints. The optimum solution is the feasible solution with the lowest total cost, i.e., vehicle 1 (aircraft) going from base 1 to base 2 and returning to base 1, and vehicle 2 going from base 1 to base 3 to base 4 and returning to base 1. The total cost is shown to be $6,800.

Computer solutions. In order to solve the pilot problem with the RIP30C program, it was necessary to set up the problem in the following standard format:

$$\text{Minimize:} \quad \sum_{j=1}^{N} C_j X_j$$

$$\text{Subject to:} \quad b_i + \sum_{j=1}^{N} a_{ij} X_j \geq 0 \qquad i = 1, 2, 3, \ldots N$$

$$x_j = 0 \text{ or } 1$$

This standard format required that all the constraints of the basic model be formulated using "greater than or equal to" signs as shown in Appendix B. The same problem is also presented in the standard format required by the computer. This change resulted in increasing the number of constraints over that which was required by the basic model.

Approximately eight hours were needed to manually set up the constraints, compute the variable coefficients, and type the matrices into an accessible file for the RIP30C program. Additionally, the variables had to be renumbered consecutively, i.e., X_{121} became X_1, X_{131} became X_2, etc.

The pilot problem was manually put into the RIP30C program and was successfully solved. The solution confirmed that the model was valid and appropriate to the problem solution. Different solutions were obtained as the constraint requirements were varied indicating the applicability of the model to sensitivity analysis.

FORTRAN Program

The time required to manually set up the pilot problem was considerable. Likewise, a considerable amount of time was expended each time a vehicle was added to or deleted from the system during the sensitivity analysis.

Unfortunately, the coefficients of the variables being eliminated could not be simply dropped from the matrix. The coefficient matrix had to be completely redefined before it would be accepted by the RIP30C program. Although this effort was reasonable for the validation process, it was apparent that this amount of set up time would seriously hamper any practical application of the model.

In order to alleviate this problem two FORTRAN programs were written. One program was written to develop distance matrices for both the global statute miles (air routes) and the surface statute miles between the various bases and between each base and the ALC. This program accepts the distances in free format and generates the distance matrices in the format required by the second FORTRAN program.

The second FORTRAN program was written to generate the input data file for use with the RIP30C program. This program automatically computes all cost coefficients for the objective function and the time requirements for each vehicle on each route for the time constraint statements. This information is then stored in a matrix of the proper format for use by the RIP30C program. A complete listing of both programs is presented in Appendix A.

A complete set of instructions is also provided in Appendix A. This is a step-by-step outline of the procedures which must be followed during the solution process.

The solution obtained by using the FORTRAN generated matrices in the RIP30C program is precisely the same as was obtained by using the RIP30C program alone (manually generated and inputed data matrices). The optimum solution variables are printed below the "Least Z Before Variable Change" line in the solution output as shown in the pilot problem solution in Appendix B. The solution variables are listed as variable indexes and refer to the subscripts shown in the data input for the pilot problem. For example, variable index 11 refers to variable subscript 132, which indicates that one of the solution variables is the use of vehicle number 2 between base 1 and base 3. The time and cost of each individual variable is also shown.

<u>Summary</u>. The FORTRAN programs reduced the time for generation of a solution matrix from approximately eight hours to about fifteen minutes. The most beneficial aspect of these FORTRAN programs, however, is their accuracy. This accuracy is insured through the simplicity of the manner in which the programs receive the inputs from the user.

Figure 2 provides a complete overview of the computational programs used in the solution process.

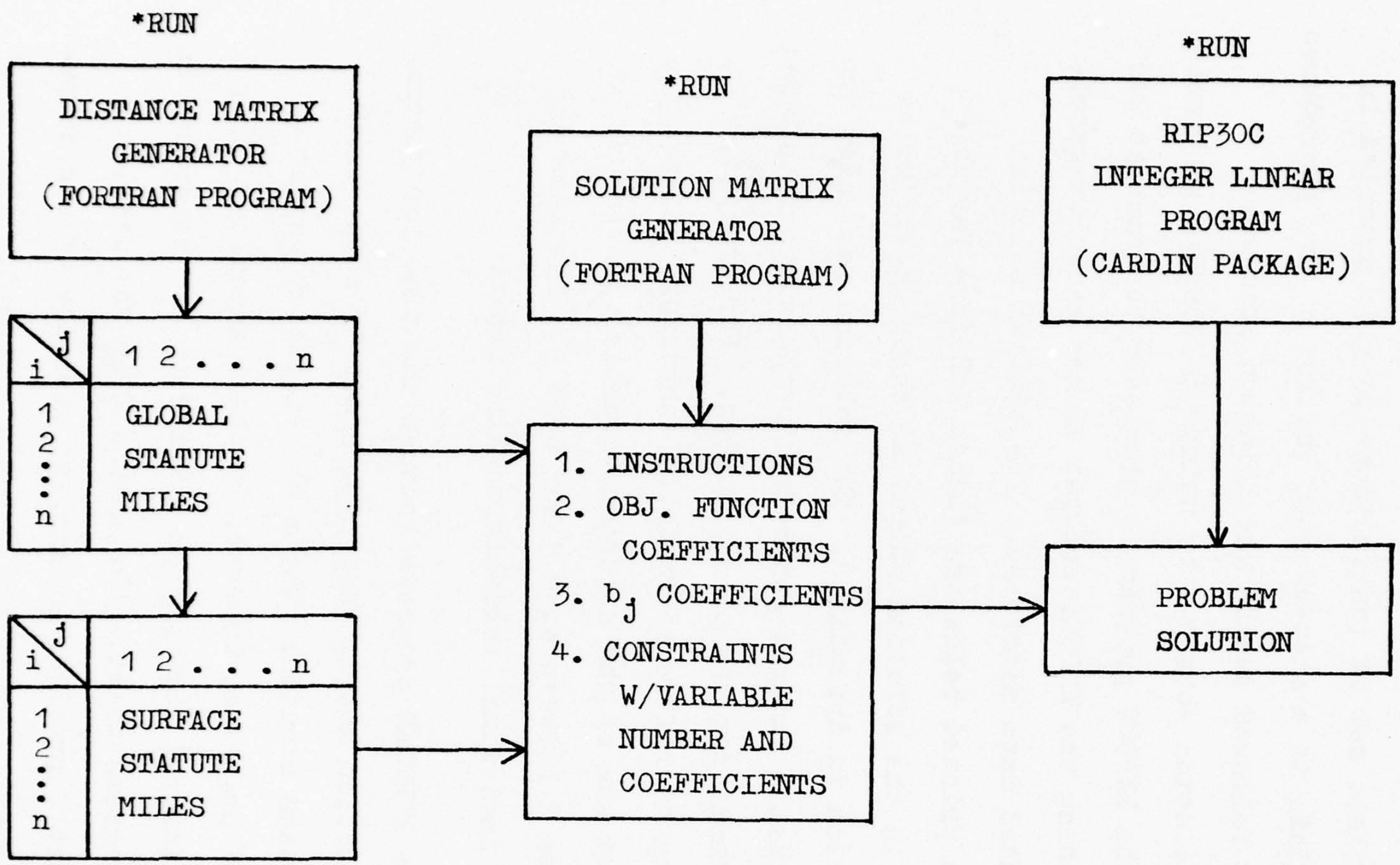


Figure 2

Computational Programs

Model Efficiency

The basic model utilizing two-way arcs will develop only optimal solutions when used within the confines of given computer limits. This is because all possible route combinations are considered in each problem formulation. Under certain conditions, however, the basic model will also develop infeasible solutions due to the possibility of a vehicle looping[3] between two customer bases. Problems formulated with the one-way model, on the other hand, may not produce an optimal solution, depending upon the method by which bases are numbered for the problem formulation, but will always develop a feasible solution.

It was decided to pursue the objective of this research effort utilizing the basic model with the one-way restriction for two reasons: (1) the greater efficiency of the model with the one-way restriction,[4] and (2) the apparent power of the model to consistently produce optimal or very near optimal solutions. This last statement is supported by the results obtained from the example problems.

---

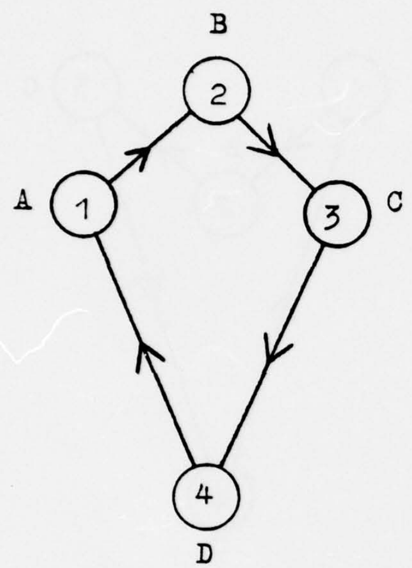
[3]The solution is infeasible because it does not provide a connecting route to or from the ALC.

[4]Computer time will always be limited, whether by capacity or by other resources. Since the objective is to develop a mathematical computer model to minimize the feeder route costs it is felt that the more customer bases and vehicles which can reasonably be considered at the same time will ultimately lead to the lowest overall costs.

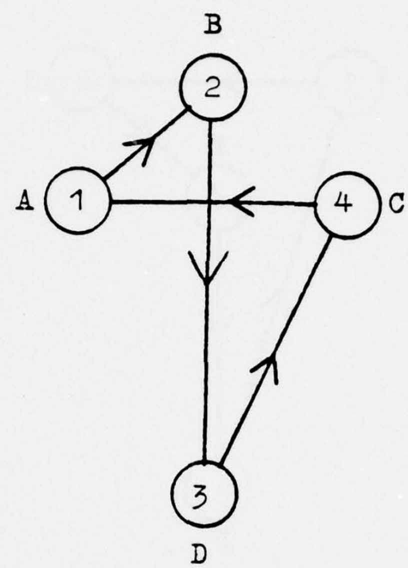
In most cases the solutions obtained with the one-way restriction appear to be optimal. Sub-optimal solutions which were obtained, fell into two general types, both of which were attributed to the method of numbering the bases in the network. These general types are depicted in Figures 3 and 4.

The sub-optimal solution depicted in Figure 3 is the least consequential of the two types because it is easily spotted by inspection. The key to the sub-optimality is that the vehicle crosses its own path. Whenever this occurs, the bases in the affected route should be re-numbered to eliminate the crossed path. The revised solution should then be optimal.

One of the solutions depicted in Figure 4 is a sub-optimal solution of the second type. From the information presented, it is impossible to determine if (a) or (b) is the better solution unless the distances are measured. Again the determination of a possible sub-optimal solution must be made by inspection. If it is determined that the possibility exists, then the bases involved should be re-numbered and the problem re-solved. Experience with this type of solution indicates that in order to insure an optimal solution, base B, which is common to both triangles DBC and ABC, should be re-numbered at least three different times.



(a) Optimal Solution



(b) Sub-Optimal Solution

Figure 3

Example of Varying Solution by Choosing a

Different Numbering Scheme

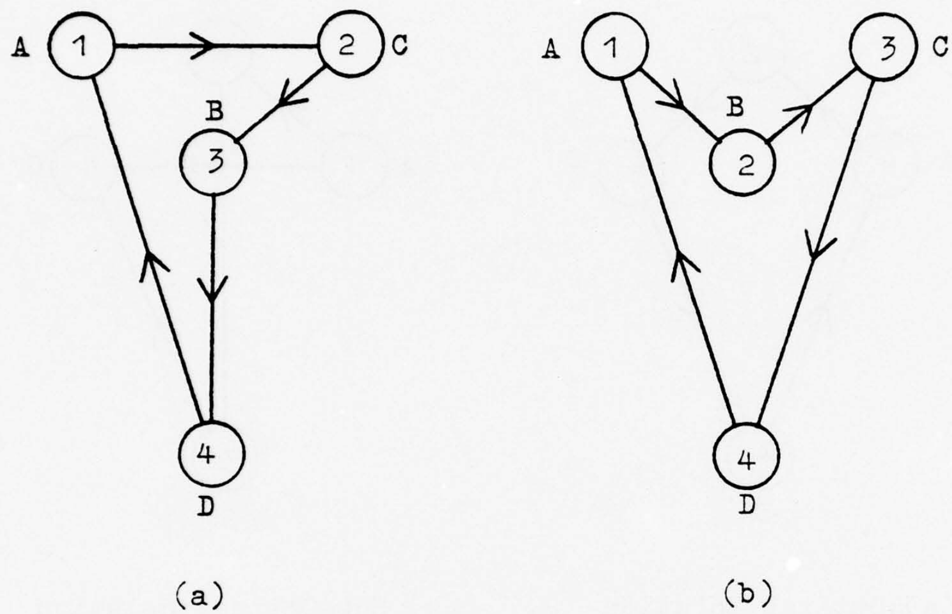


Figure 4

Example of Varying Solution by Choosing a Different Numbering Scheme

Base B should be given the highest number in its cluster, the lowest number in its cluster, and then the number it would receive if the bases were numbered sequentially.

Summary. Although the problem of sub-optimality does not seriously limit the use of the model, it must nonetheless be considered. There are two possibilities for overcoming this limitation: (1) increase computer time and memory space for the size problem necessary to solve the basic (two-way) model, or (2) use a logical numbering system. The first possibility should not be completely ruled out. LOGAIR contracts are awarded on a yearly basis and as such, may be of sufficient importance to warrant a large block of computer time and space to guarantee optimality. The second method, although heuristic, costs very little to implement. A logical numbering system dictates that the bases be assigned numbers in a continuous clockwise (or counter-clockwise) manner. If a cluster of bases does not form a naturally circular path or other natural pattern, the problem should be run with different numbering systems and scrutinized for the general type of sub-optimal solutions as previously mentioned.

Summary of Limitations

1. The model requires the LOGAIR feeder networks to have specified depot and customer bases, as it will only be optimal for a given set of nodes.

2. Computer core space available for the solution of the LOGAIR model was limited to 65K. This limitation subsequently limited the size of problems which could be solved during this research effort to a maximum of 150 variables and 100 constraints.

3. Infeasible solutions occurred with the basic model due to looping between bases. This problem was eliminated with a modification to the basic model.

4. Data inputs into the FORTRAN matrix generators are subject to the following limitations:

A. Format statements in the program allow for a maximum cost coefficient of 9999.9999. Any figure higher than this will be truncated from the left side. Once the matrix is generated, however, the lost digit(s) can be manually replaced prior to running the RIP30C program.

B. During the compilation of the cost coefficients a distinction is made between air and surface transportation. This distinction is based solely upon vehicle per mile costs. Vehicles with a per mile cost in excess of $2.00 have an additional cost of $250.00 (landing fee) added to the product of leg length and per mile costs. It was felt that $2.00 provided a safe distinction between air and surface transportation costs for the purpose of including the landing fee.

A caution must therefore be observed: In the event a surface vehicle's per mile cost exceeds $2.00, a landing fee of $250.00 must be manually subtracted from the cost coefficients prior to running the RIP30C program, or the program must be altered. A similar, but opposite, problem will occur in the event an aircraft per mile cost is less than $2.00.

C. The time computed for a vehicle on a leg of the network includes an additive constant to allow for loading and unloading time, refueling, and taxi time (aircraft). These additive constants, which are "best" estimates, are one hour for aircraft and three hours for trucks.

Chapter 4

RESULTS

General

LOGAIR Route 5R of the FY 76 LOGAIR system was chosen for analysis to complete the third and final phase of validation of the model. In an attempt to thoroughly test the versatility of the model the results of model solutions obtained by varying performance level, vehicle mix, and the daily demand were compared. Experiments with changes which would expand the possibilities of the model but not contribute to increased demands upon the computer system were conducted. Such manipulations consisted of (1) doubling per mile costs and capacity of vehicles entered into the system, and (2) changing requirements to indicate vehicles visiting bases every other day. This first manipulation has the effect of doubling the number of vehicles being considered to increase capacity. Because the vehicles are considered in pairs this does not increase the number of variables in the problem formulation. This technique would be of assistance in formulating a problem consisting of bases with very large demands (ALC network). The second manipulation of visiting some bases every other

day would be of assistance in formulating a problem with bases with small daily demands.

<u>Phase analyses</u>. The number of computer runs that would be necessary to conduct all of the sensitivity analysis of interest is enormous. In order to cover the widest possible spectrum in the time available, an ordered method of conducting the analysis was required. The plan which was decided on involved a series of four phases of analysis; each phase being a building block for the rest.

The plan resulted in a reduction in the number of options which needed to be investigated. It was obvious after several runs that problems were not constrained by time limits greater than 15 hours for aircraft or 84 hours for surface traffic. Constraint times greater than these limits were subsequently eliminated. The time constraints for surface vehicles used in the majority of test runs were 36, 60, and 84 hours.[1] The time constraint of 15 hours for air service is constant for all problem formulations in this chapter.

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[1]These times correspond to delivery times of 24, 48, and 72 hours (one, two, and three days) to the last base on any route selected; the difference of 12 hours is an allowance for the time required to travel from the last base back to the ALC with three hours of loading/unloading time at the ALC. This last leg of each route, though it is not considered for timing purposes, must nonetheless be included for its overall cost contribution.

It was decided to limit the consideration of TP3 cargo in the demand requirements in order to better compare the results of the computer generated solutions with the present route costs. (The LOGAIR system presently is designed to ship TP1 and 2 cargo on a demand basis, and TP3 cargo on a space available basis). TP3 cargo[2] was considered in several instances to determine the effect of this additional demand on the overall costs.

Results of Analyses

Phase I initially considered aircraft as the only vehicles, and then considered surface vehicles only.[3] The purpose was to determine which vehicles of each type were the most cost effective. These results were used in a later analysis which considered the air and surface vehicles in combination. Consideration was directed at reducing the number and type of vehicles which must be considered for further analysis.

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[2]The entire TP3 cargo demand was considered, as well as only the "big" TP3 cargo. "Big" cargo is defined as that which cannot go by conventional means (UPS, REA, Parcel Post, etc.) (7).

[3]The aircraft considered were the L100, L188, and DC-9. Surface vehicles were 45, 40, 28, and 18 LF (Longitudinal Feet) trucks.

Initially all types of aircraft and trucks were considered in the formulations of the problems. Runs were also made using TP1 and 2 demands only and TP1, 2, and 3 demands. The results of these runs indicate that certain vehicles favored certain loads due to compatibility of capacity with demand. The vehicles[4] which were in the optimum solutions when considering only TP1 and 2 cargo demands were: (1) the L188 aircraft, (2) the 40 LF truck, (3) the 28 LF truck, and (4) the 18 LF truck. The vehicles which were in the optimum solutions when considering TP1, 2, and 3 cargo demands were: (1) the L188 aircraft, (2) the DC-9 aircraft, (3) the 40 LF truck, and (4) the 28 LF truck. Based on these observations, it was decided to consider only these vehicles in most of the succeeding analysis.

Phase II analysis was designed to investigate the utility of the different options available in the RIP30C program. This type of analysis is important if desired to know what options should be selected under what prevailing circumstances in order to obtain a solution in minimum time.

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[4]The LOGAIR route 5R is presently serviced by the L188 aircraft only. Using the standard costing as presented in Appendix C, the cost of this operation, as determined by this program, is $5,600 per day. This cost figure is therefore defined as the reference for this route.

This series of runs investigated the use of the program options, both singly and in combination. The problem was formulated with two, three, and four vehicles in order to determine the relationships between the number of problem variables and the computer run time for each option. Results of these runs are included in Appendix D. The program options are described below:

1. LP Start Option. This option causes the RIP30C program to first solve for a continuous solution by linear programming and takes the initial partial solution as one determined by variables which have a value of "zero or one." The overall effect is to examine all roundings of the continuous solution first.

2. Augmentation Option. This option specifies a modification of Balas',[5] Rule whereby only "free variables corresponding to fractional dual variables of (LPs) are considered as candidates [6:3]."

3. Imbedded LP Option. This option allows for internal LP solutions at selected intervals in the enumeration process[6] to assist and accelerate the fathoming process by developing surrogate constraints.

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[5] Egon Balas' algorithm for solving binary linear programming problems.

[6] LP solution frequencies of one and eight were recommended by the user's manual.

4. Number of Surrogate Constraints. The RIP30C user's manual recommends a maximum of four surrogate constraints.[7]

The Phase II analysis indicated that for problems consisting of seven bases (such as the LOGAIR Route 5R) and two vehicles (54 variables and 46 constraints), the imbedded LP (Linear Programming) option (frequency = 8) and the augmentation options would generally provide the fastest solutions. The same seven node problem, but with three vehicles (81 variables and 62 constraints) yielded to any combination of options which included the LP option. Once the problem size was further increased to four vehicles (108 variables and 78 constraints), feasible solutions could not be obtained with the imbedded LP option (either frequency) taken singly, or in combination. It was concluded that the imbedded LP option and the augmentation option, when paired together, provided the fastest solution times for problems consisting of seven nodes and three or less vehicles. The LP start option appeared to provide the best solution times for larger problems. Figures 5 and 6 show the relationships between the number of variables and run

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[7]Description of RIP30C options from user's manual (6:2-3).

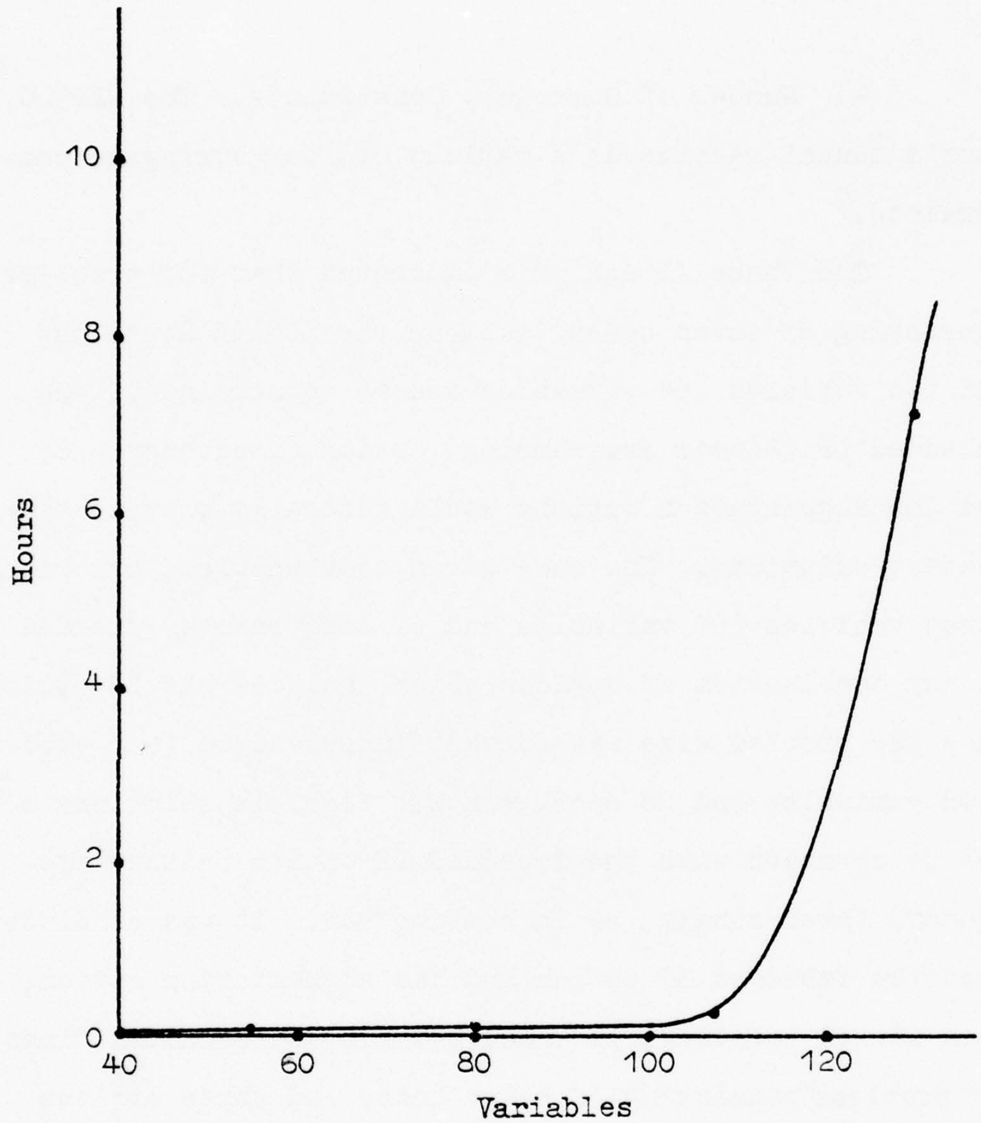

Figure 5

Run Time[1] Vs Variables
(LP Start Option Only)

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[1]LP start option produced fastest solution times for problems greater than 108 variables.

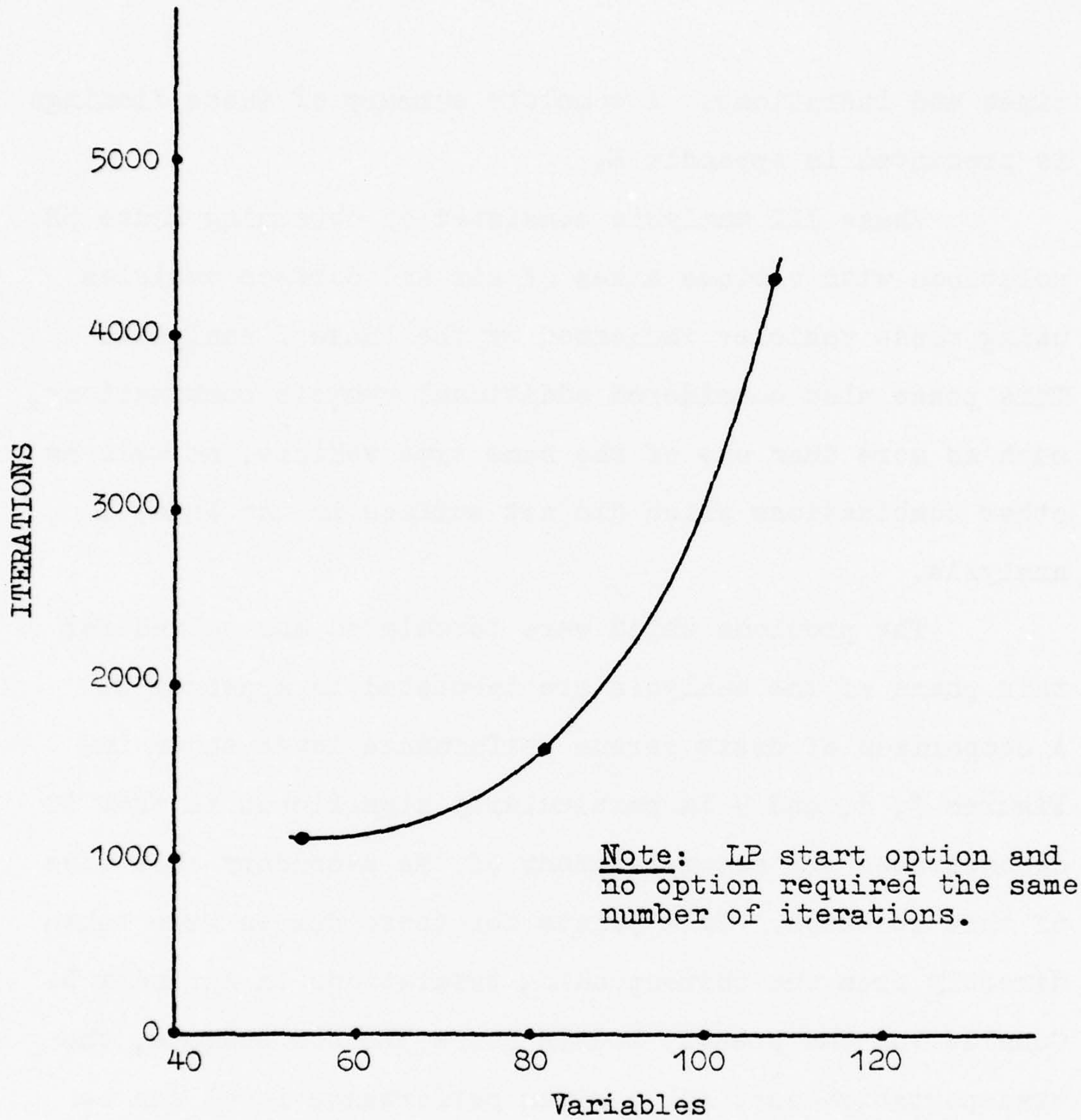


Figure 6

Iterations[1] Vs Variables
(LP Start and No Option Only)

---

[1]Problems with greater than 81 variables could be solved with LP start option or no option only. Problems with 132 variables required approximately 33,000 iterations (largest problem solved).

times and iterations. A complete summary of these findings is presented in Appendix E.

Phase III analysis consisted of obtaining Route 5R solutions with various mixes of air and surface vehicles using those vehicles indicated by the Phase I analysis. This phase also considered additional vehicle combinations, such as more than one of the same type vehicle, as well as other combinations which did not surface in the Phase I analysis.

The problems which were formulated and solved for this phase of the analysis are tabulated in Appendix D. A comparison of costs versus performance level shown in Figures 7, 8, and 9 is particularly significant in that it demonstrates the accomplishment of the secondary objective of this research. Data points for these curves were taken directly from the corresponding tabulations in Appendix D. Considering the present LOGAIR Route 5R, for example, the transportation cost for a given performance level can be accurately gauged. A similar assessment of inventory costs versus performance level (taken in concert with the former) would yield an accurate estimate of a very large proportion of the total distribution costs for this route.

Phase IV consisted of computer runs which were made to demonstrate other capabilities of the model such as:

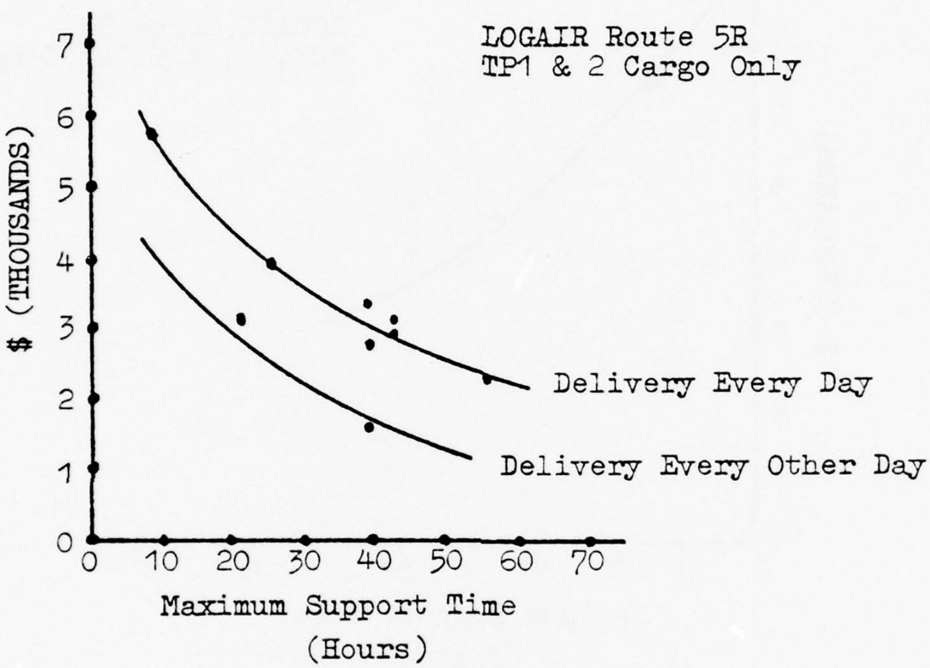


Figure 7

Daily Cost Vs Performance Level, TP 1&2.

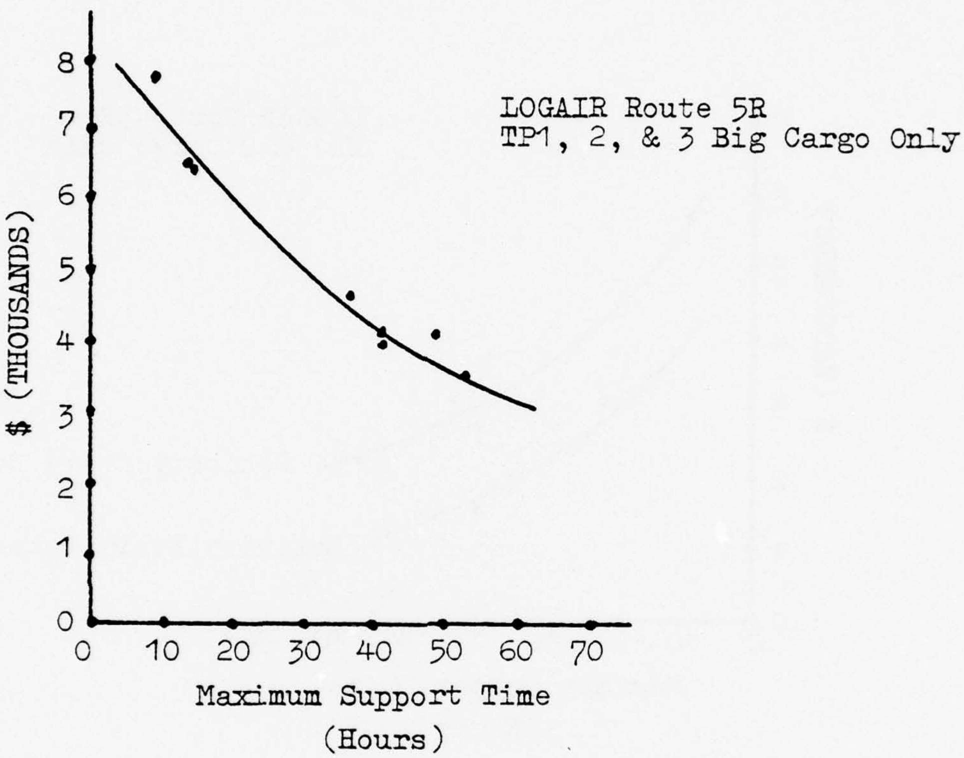


Figure 8

Daily Cost Vs Performance Level,
TP 1,2,&3 Big

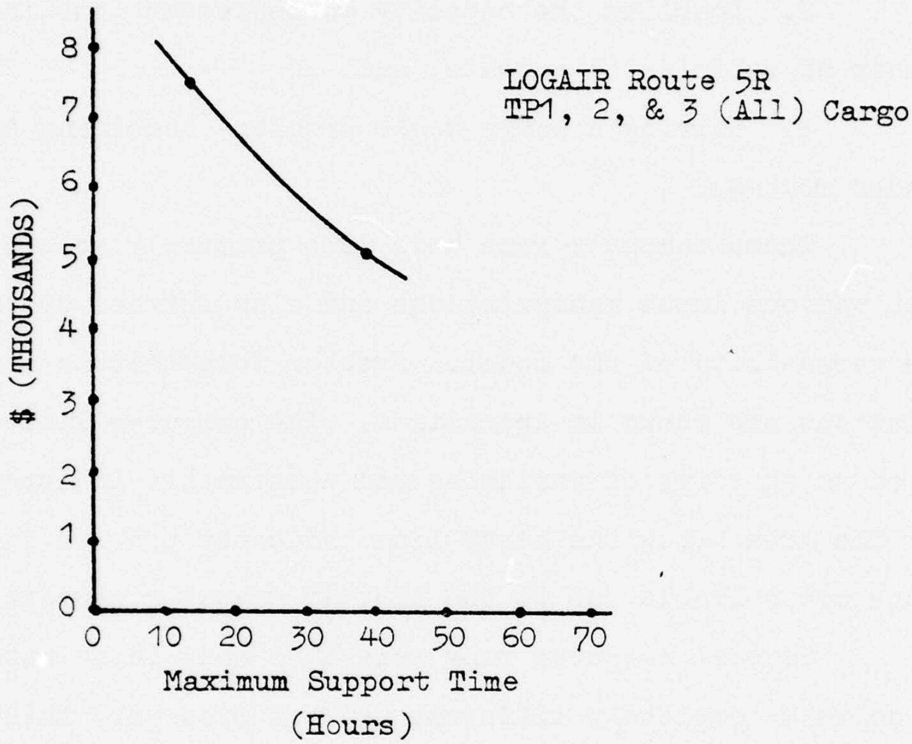


Figure 9

Daily Cost Vs Performance Level ,

TP 1,2,&3

1. Doubling the daily demands as if delivery would take place every other day,

2. Doubling the capacity to represent doubling the number of vehicles on a route, and

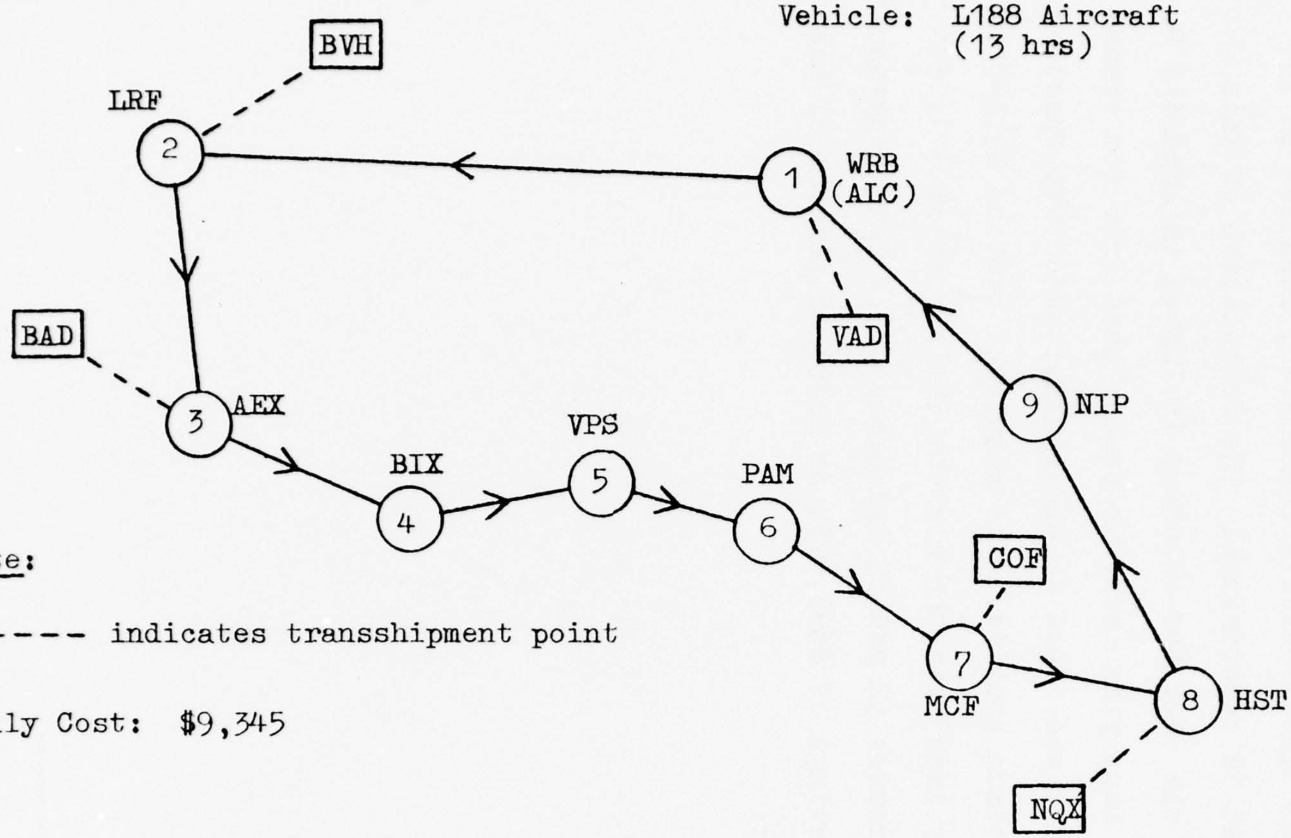
3. Solving a large scale problem (combining existing feeder routes).

These computer runs were made primarily to experiment with various input manipulations and also further demonstrate the versatility of the model. Problem formulations and solutions are shown in Appendix D. The computer limitation, is shown in terms of variables and constraints in Appendix E. The area below the heavy line indicates problem formulations not solvable due to the limited computer storage.

Several computer runs were also made in an attempt to solve a completely different network problem. This problem was a combination of feeder routes 5R and 5Q. The purpose was to demonstrate the capability to solve larger network problems, i.e., to optimize a network with a significantly larger number of bases considered simultaneously. The air and ground distance matrices and the daily demands of the bases in route 5Q are listed in Appendix C.

Because of the core space limit the combination problem could not be formulated without arbitrarily designating four bases as transshipment points (Figure 10). This

Vehicle: L188 Aircraft
(13 hrs)



<u>Note:</u>

◯- - - - indicates transshipment point

Daily Cost: $9,345

Figure 10

Combined Routes 5R and 5Q

problem, with three vehicles considered, resulted in 132 variables and 78 constraints. The formulation of this problem and the computer solution is listed in Appendix D. The cost of supplying each sub-feeder base from its transshipment point was added to the minimum objective function value at optimum routing. The resultant cost of $9,345 is considerably less than the present daily cost of $11,160[8] to operate routes 5R and 5Q independently. This represents an annual savings of $662,475, or about 16 percent of the present cost.

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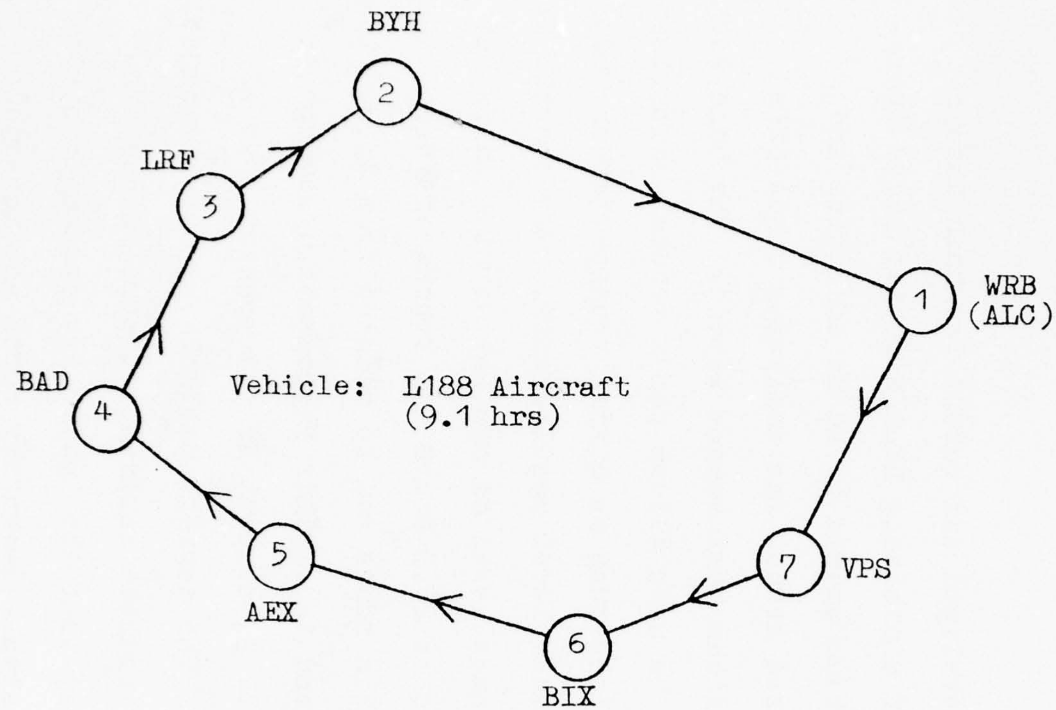
[8]This figure was obtained by calculating the present cost of operating route 5Q by use of the cost factors shown in Appendix C. This cost was added to the present cost of operating route 5R (previously calculated).

Chapter 5

CONCLUSION

Summary

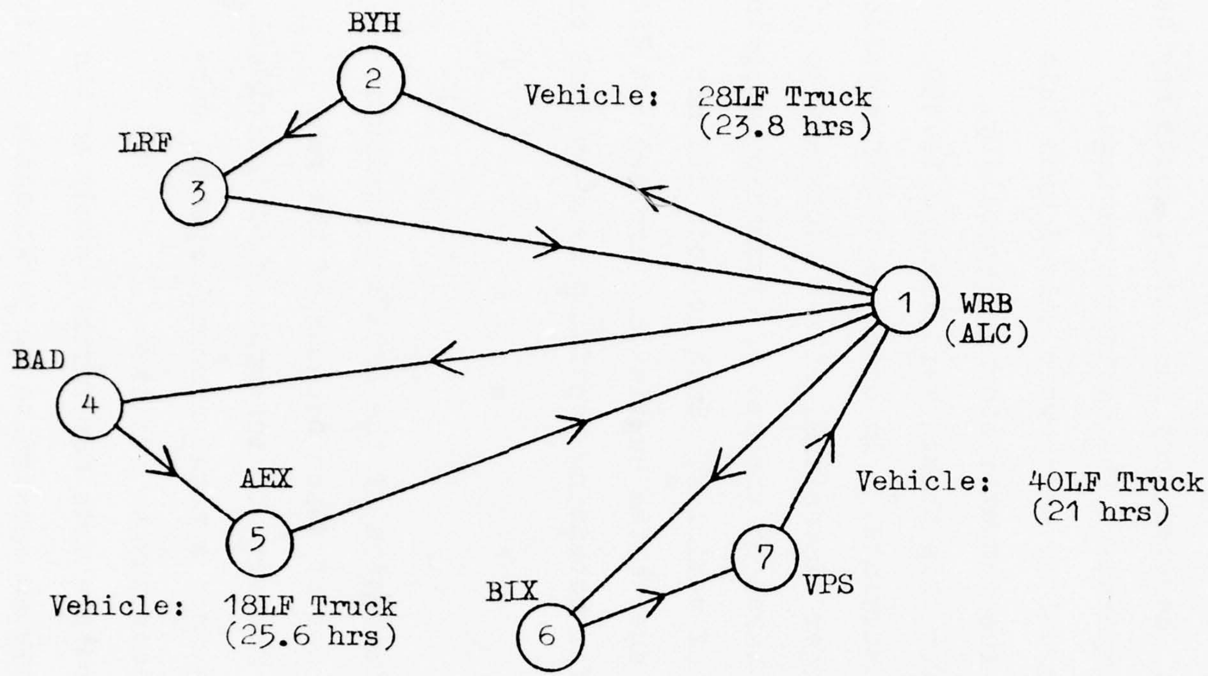
The model developed and tested for this thesis provides a method of minimizing LOGAIR feeder route transportation costs. It has proven to be an effective and efficient computerized method for analyzing trade-offs between cost and various performance levels. The ease with which the model may be used allows for a general comparison of distribution options such as mixing transportation modes and varying performance level requirements. For example if the desired performance level of one day service on feeder route 5R is extended to 25.6 hours and trucks are used, then the daily cost of this route can be reduced from $5,600 to $3,895 (Figures 11 and 12). This represents a savings of $622,325 per year, or 30 percent of the present cost of operating route 5R. The savings possible by the introduction of surface vehicles and the relaxing of performance constraints do not imply that the lower cost system is better than the present system. Inventory costs and materials handling costs need also to be analyzed. In addition, the impact of transportation performance on mission capability



Daily Cost: $5,600
Time is to Last Base on
Route, Excluding ALC

Figure 11

Present Route 5R



Daily Cost: $3,895
Time is to Last Base on Route,
Excluding ALC

Figure 12

Computer Route 5R

should be considered. However, any additional costs may be insignificant when compared to the estimated savings.

The size of problems which were solved with this model are limited by the computer storage capability. Problems formulated for this thesis were limited to 150 variables and 100 constraints.[1] In order to obtain solutions for problems with larger dimensions, it was necessary to reduce the number of bases by the use of transshipment points or reduce the number of vehicles. Such methods did not guarantee optimality due to the hueristics involved but did provide a technique for obtaining hopefully near-optimal or optimal solutions.

Recommendations

Complete optimization of the LOGAIR distribution system appears to be out of reach because of the many variables involved. However, by integration of individual optimal feeder routes into a total aircraft system, substantial cost reductions may be realized.

The most lucrative area for further study of the LOGAIR distribution system appears to be performance requirements. As was shown in this study, considerable savings can

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[1]The RIP30C program must be re-dimensioned to take advantage of increased computer capability.

be achieved by relaxing the performance requirements and allowing expanded usage of surface transportation. A feasibility study to determine what effects the relaxing of performance requirements will have on combat capability and mission effectiveness is desired.

It is recommended that this model be used as an aid in designing future feeder routes in the LOGAIR system.

APPENDIX A

FORTRAN PROGRAMS

```
C DISTANCE MATRIX GENERATION
CALL ATTACH(21,"77A71/DISTEST;",3,0,,)
CALL ATTACH(31,"77A71/DISTESTG;",3,0,,)
N=4
PRINT,"HAVE YOU CHANGED DIMENSION TO DISAIR(NN). DISGND(NN)?"
DIMENSION DISAIR(4,4),DISGND(4,4)
DO 10 I=1,N-1
DO 16 J=I+1,N
READ,DISAIR(I,J)
DISAIR(J,I)=DISAIR(I,J)
16 CONTINUE
10 CONTINUE
DO 20 I=1,N-1
DO 25 J=I+1,N
READ,DISGND(I,J)
DISGND(J,I)=DISGND(I,J)
25 CONTINUE
20 CONTINUE
PRINT,"       "
PRINT,"DISTANCE MATRIX GENERATED IS:"
PRINT,"    "
PRINT,"    "
PRINT,"*******************************************"
PRINT,"      (I TO J) AIR DISTANCE"
PRINT,"*******************************************"
PRINT,"     "
DO 30 I=1,N
WRITE(21,100)(DISAIR(I,J),J=1,N)
PRINT 100,(DISAIR(I,J),J=1,N)
30 CONTINUE
PRINT,"*******************************************"
PRINT,"   (I TO J) SURFACE DISTANCE"
PRINT,"*******************************************"
PRINT,"    "
DO 40 I=1,N
WRITE(31,100)(DISGND(I,J),J=1,N)
PRINT 100,(DISGND(I,J),J=1,N)
40 CONTINUE
100 FORMAT(7(1X,F7.2,1X))
STOP
END
```

Figure 13

FORTRAN Program for Distance Matrices

```
1000C LOGAIR FEEDER ROUTE MATRIX GENERATOR
1010 CALL ATTACH(21,"77A71/DISTEST;",3,0,,)
1015 CALL ATTACH(31,"77A71/DISTESTG;",3,0,,)
1020 CALL ATTACH(11,"77A71/LOG5R;",3,0,,)
1030 PRINT,"ENTER TOTAL NODES(# BASES + ALC)=INTEGER(N)"
1040 READ,N
1050 PRINT,"ENTER TOTAL # VEHICLES=INTEGER(M)"
1060 READ,M
1070C NUMBER OF BASIC VARIABLES = NBV
1080 NBV=M*9
1090C NUMBER OF CONSTRAINTS = NCON
1100 NCON=((4*M)+(2*N)+(2*M*(N-1)))
1110 PRINT,"ENTER # VARIABLES IN INITIAL PARTIAL SOLUTION=OPTION 1"
1120 READ,NOPT1
1130 PRINT,"ENTER = 0,IF NO IMBEDDED LP; 1,IF OTHERWISE"
1140 READ,NOPT2
1150 PRINT,"ENTER = 0,IF COEFF SIGNS NORMAL; 1,IF SIGNS REVERSED"
1160 READ,NOPT3
1170 PRINT,"ENTER = 0,FOR INTERMEDIATE OUTPUT TO APPEAR; 1,IF OTHERWISE"
1180 READ,NOPT4
1190 PRINT,"ENTER = 0,IF COST COEFF ALL INTEGER; 1, IF OTHERWISE"
1200 READ,NOPT5
1210 PRINT,"ENTER = 0,OR OTHER AUGMENTATION RULE"
1220 READ,NOPT6
1230 PRINT,"ENTER FREQUENCY OF INTERMEDIATE OUTPUT = INTEGER"
1240 READ,NOUT
1250 PRINT,"ENTER = 0,OR UPPER BOUND IF KNOWN"
1260 READ,NBND
1270 PRINT,"ENTER = 0,OR MAX # SURROGATE CONSTRAINTS, IF KNOWN"
1280 READ,NSUR
1290 PRINT,"ENTER = 0,OR FREQUENCY OF IMBEDDED LP"
1300 READ,NLP
1310 PRINT,"ENTER MAX TIME IN SECONDS"
1320 READ,NSEC
1330 PRINT,"ENTER THE NUMBER OF THIS PROBLEM RUN- LOGAIR__"
1340 READ,NAME
1350 NM=N*M
1360 PRINT,"DIMENSION STATEMENT LINENO 1420,1430,1440 MAY REQUIRE REVISION"
1370 PRINT,"IF SO, UTILIZE FOLLOWING GUIDE TO UPDATE DIMENSIONS:"
1380 PRINT,"                    "
1390 PRINT,"CIJK(NNM), TIJK(NNM), WJ(N), VJ(N), TK(M), WK(M), VK(M),"
1400 PRINT,"DISAIR(NN), DISGND(NN), KX(NNM), RATE(M), COST(M),"
1410 PRINT,"BA(N),BB(N),BC(M),BD(N),AA...AF(4)"
1420 DIMENSION CIJK(4,4,2),TIJK(4,4,2),WJ(4),VJ(4),TK(2),WK(2),VK(2)
1430 DIMENSION DISAIR(4,4),DISGND(4,4),KX(4,4,2),RATE(2),COST(2)
1440 DIMENSION BA(4),BB(4),BC(2),BD(4),AA(4),AB(4),AC(4),AD(4),AE(4),AF(4)
1450 PRINT,"ENTER WEIGHT DEMANDS FOR BASES 1,2,....,J"
1460 READ,(WJ(J),J=1,N)
1470 PRINT,"ENTER VOLUME DEMANDS FOR BASES 1,2,....,J"
1480 READ,(VJ(J),J=1,N)
1490 PRINT,"ENTER VEHICLE WEIGHT CONSTRAINTS FOR VEHICLES 1,2,....'"
```

Figure 14

FORTRAN Program for Solution Matrix

```
READ,(WK(K),K=1,M)
PRINT,"ENTER VEHICLE VOLUME CONSTRAINTS FOR VEHICLES 1,2,....,M"
READ,(VK(K),K=1,M)
PRINT,"ENTER VEHICLE TIME CONSTRAINTS FOR VEHICLES 1,2....,M"
READ,(TK(K),K=1,M)
READ(21,55)((DISAIR(I,J),J=1,N),I=1,N)
READ(31,55)((DISGND(I,J),J=1,N),I=1,N)
PRINT,"ENTER VEHICLE SPEEDS, MILES/HR, IN ORDER VEHICLES 1,2,....,M"
DO 10 K=1,M
READ,RATE(K)
IF(RATE(K).LT.100) GO TO 20
DO 30 I=1,N
DO 30 J=1,N
TIJK(I,J,K)=(DISAIR(I,J)/RATE(K))+1.0
30 CONTINUE
GO TO 10
20 DO 40 I=1,N
DO 40 J=1,N
TIJK(I,J,K)=(DISGND(I,J)/RATE(K))+3.0
40 CONTINUE
10 CONTINUE
PRINT,"ENTER VEHICLE PER MILE COSTS IN ORDER OF VEHICLE 1,2,....,M"
DO 50 K=1,M
READ,COST(K)
IF(COST(K).LT.2.00) GO TO 60
DO 70 I=1,N
DO 70 J=1,N
CIJK(I,J,K)=(DISAIR(I,J)*COST(K))+250.00
70 CONTINUE
GO TO 50
60 DO 80 I=1,N
DO 80 J=1,N
CIJK(I,J,K)=DISGND(I,J)*COST(K)
80 CONTINUE
50 CONTINUE
C FOLLOWS FIRST LINE AND COST COEFF TO SOLUTION MATRIX
LINO=1000
WRITE(11,5)LINO,NCON,NBV,NOPT1,NOPT2,NOUT,NBND,NSUR,NLP,
&NOPT3,NSEC,NOPT4,NOPT5,NOPT6,NAME
LINO=LINO+10
LA=1
DO 100 K=1,M
DO 110 I=1,N
DO 120 J=1,N
IF(I.GE.J) GO TO 120
CALL CSTCOEF(LINO,LA,AA,CIJK(I,J,K))
120 CONTINUE
110 CONTINUE
DO 100 I=2,N
J=1
```

Figure 14 (continued)

```
2000 CALL CSTCOEF(LINO,LA,AA,CIJK(I,J,K))
2010 100 CONTINUE
2020 IF(LA.EQ.1) GO TO 124
2030 WRITE(11,15)LINO,(AA(LZ),LZ=1,LA-1)
2040 LINO=LINO+10
2050C FOLLOWS B COEFF TO SOLUTION MATRIX
2060 124 LB=1
2070 DO 125 K=1,M
2080 CALL BCOEF(LINO,LB,AB,TK(K))
2090 125 CONTINUE
2100 DO 130 L=1,N
2110 BA(L)=-1.
2120 CALL BCOEF(LINO,LB,AB,BA(L))
2130 130 CONTINUE
2140 DO 140 L=1,N
2150 BB(L)=1.
2160 CALL BCOEF(LINO,LB,AB,BB(L))
2170 140 CONTINUE
2180 DO 150 K=1,M
2190 BC(K)=0.
2200 CALL BCOEF(LINO,LB,AB,BC(K))
2210 150 CONTINUE
2220 DO 160 K=1,M
2230 CALL BCOEF(LINO,LB,AB,WK(K))
2240 160 CONTINUE
2250 DO 170 K=1,M
2260 CALL BCOEF(LINO,LB,AB,VK(K))
2270 170 CONTINUE
2280 MB=2*M*(N-1)
2290 DO 180 L=1,MB
2300 BD(L)=0.
2310 CALL BCOEF(LINO,LB,AB,BD(L))
2320 180 CONTINUE
2330 IF(LB.EQ.1) GO TO 184
2340 WRITE(11,15)LINO,(AB(LZ),LZ=1,LB-1)
2350 LINO=LINO+10
2360C FOLLOWS TRANSFORM OF BAS VARS FROM SUBSCRIPTED TO CONSECUTIVE NUMBERS
2370 IJK=0
2380 184 LC=1
2390 PRINT,"     "
2400 PRINT,"***************    *****************    **********    **********"
2410 PRINT,"IJK SUBSCRIPT #    VARIABLE INDEX #    TIME(TIJK)    COST(CIJK)"
2420 PRINT,"***************    *****************    **********    **********"
2430 PRINT,"            "
2440 DO 190 K=1,M
2450 DO 200 I=1,N
2460 DO 210 J=1,N
2470 IF(I.GE.J) GO TO 210
2480 IJK=IJK+1
2490 KX(I,J,K)=IJK
```


Figure 14 (continued)

```
PRINT 25,I,J,K,IJK,TIJK(I,J,K),CIJK(I,J,K)
210 CONTINUE
200 CONTINUE
DO 220 I=2,N
J=1
IJK=IJK+1
KX(I,J,K)=IJK
PRINT 25,I,J,K,IJK,TIJK(I,J,K),CIJK(I,J,K)
220 CONTINUE
190 CONTINUE
C FOLLOWS WRITING TIME CONSTRAINTS TO SOL MATRIX
KC=0
DO 230 K=1,M
KC=KC+1
DO 240 I=1,N
DO 250 J=1,N
IF(I.GE.J) GO TO 250
T=(-1.)*TIJK(I,J,K)
CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),T)
250 CONTINUE
240 CONTINUE
DO 260 I=2,N
J=1
T=(-1.)*TIJK(I,J,K)
CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),T)
260 CONTINUE
230 CONTINUE
C FOLLOWS WRITING MIN VISIT CONSTRAINTS TO SOL MATRIX
DO 270 J=1,N
KC=KC+1
DO 280 I=1,N
DO 290 K=1,M
IF(I.GE.J) GO TO 290
CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),1.0)
290 CONTINUE
280 CONTINUE
IF(J.GE.2) GO TO 270
DO 300 I=2,N
DO 310 K=1,M
CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),1.0)
310 CONTINUE
300 CONTINUE
270 CONTINUE
DO 320 J=1,N
KC=KC+1
DO 330 I=1,N
DO 340 K=1,M
IF(I.GE.J) GO TO 340
CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),-1.0)
340 CONTINUE
```

Figure 14 (continued)

```
3ØØØ 33Ø CONTINUE
3Ø1Ø IF(J.GE.2) GO TO 32Ø
3Ø2Ø DO 35Ø I=2,N
3Ø3Ø DO 36Ø K=1,M
3Ø4Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),-1.Ø)
3Ø5Ø 36Ø CONTINUE
3Ø6Ø 35Ø CONTINUE
3Ø7Ø 32Ø CONTINUE
3Ø8ØC FOLLOWS WRITING OUT & BACK CONSTRAINTS TO SOL MATRIX
3Ø9Ø DO 37Ø K=1,M
31ØØ KC=KC+1
311Ø DO 38Ø I=1,N
312Ø DO 39Ø J=1,N
313Ø IF(I.GE.J) GO TO 39Ø
314Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),-1.Ø)
315Ø 39Ø CONTINUE
316Ø 38Ø CONTINUE
317Ø DO 4ØØ I=2,N
318Ø J=1
319Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),999.Ø)
32ØØ 4ØØ CONTINUE
321Ø 37Ø CONTINUE
322ØC FOLLOWS WRITING WEIGHT CONSTRAINTS TO SOL MATRIX
323Ø DO 41Ø K=1,M
324Ø KC=KC+1
325Ø DO 42Ø I=1,N
326Ø DO 43Ø J=1,N
327Ø IF(I.GE.J) GO TO 43Ø
328Ø W=(-1.)*WJ(J)
329Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),W)
33ØØ 43Ø CONTINUE
331Ø 42Ø CONTINUE
332Ø DO 44Ø I=2,N
333Ø J=1
334Ø W=(-1.)*WJ(J)
335Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),W)
336Ø 44Ø CONTINUE
337Ø 41Ø CONTINUE
338ØC FOLLOWS WRITING VOLUME CONSTRAINTS TO SOL MATRIX
339Ø DO 45Ø K=1,M
34ØØ KC=KC+1
341Ø DO 46Ø I=1,N
342Ø DO 47Ø J=1,N
343Ø IF(I.GE.J) GO TO 47Ø
344Ø V=(-1.)*VJ(J)
345Ø CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),V)
346Ø 47Ø CONTINUE
347Ø 46Ø CONTINUE
348Ø DO 48Ø I=2,N
349Ø J=1
```

Figure 14 (continued)

```
 V=(-1.)*VJ(J)
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),V)
 480 CONTINUE
 450 CONTINUE
C FOLLOWS WRITING BALANCE CONSTRAINTS TO SOL MATRIX
 DO 490 K=1,M
 DO 500 J=2,N
 KC=KC+1
 DO 510 I=1,N
 L=J
 IF(I.GE.J) GO TO 520
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),1.0)
 520 IF(L.GE.I) GO TO 510
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(L,I,K),-1.0)
 510 CONTINUE
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(L,1,K),-1.0)
 500 CONTINUE
 490 CONTINUE
 DO 530 K=1,M
 DO 540 J=2,N
 KC=KC+1
 DO 550 I=1,N
 L=J
 IF(I.GE.J) GO TO 560
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(I,J,K),-1.0)
 560 IF(L.GE.I) GO TO 550
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(L,I,K),1.0)
 550 CONTINUE
 CALL CSTRANT(LINO,LC,AC,AD,AE,KC,KX(L,1,K),1.0)
 540 CONTINUE
 530 CONTINUE
C FOLLOWS FORMAT STATEMENTS FOR SOL MATRIX
 5 FORMAT(I4,1X,I3,1X,I3,1X,I3,1X,I1,1X,I2,1X,I3,1X,I3,1X,I2,1X,
&I1,1X,I3,1X,I1,1X,I1,1X,I1,1X,6HLOGAIR,I2)
 15 FORMAT(I5,1X,4(F9.4,1X))
 25 FORMAT(5X,I2,I2,I2,13X,I5,11X,F6.2,6X,F8.2,/)
 35 FORMAT(I5,1X,4(2(I3,1X)F10.3,1X))
 45 FORMAT(I5,1X,4(F5.1,1X))
 55 FORMAT(V)
 IF(LC.EQ.1) GO TO 570
 DO 580 I=1,4
 AF(I)=000.
 580 CONTINUE
 WRITE(11,35)LINO,(AC(LZ),AD(LZ),AE(LZ),LZ=1,LC-1),(AF(I),I=LC,4)
 LINO=LINO+10
 WRITE(11,45)LINO,(AF(I),I=1,4)
 570 STOP
 END
 SUBROUTINE CSTCOEF(LINO,LA,AA,ZA)
 DIMENSION AA(10)
```

Figure 14 (continued)

```
4000 AA(LA)=ZA
4010 LA=LA+1
4020 IF(LA.LE.4) GO TO 910
4030 WRITE(11,15)LINO,(AA(LZ),LZ=1,4)
4040 LINO=LINO+10
4050 15 FORMAT(I5,1X,4(F9.4,1X))
4060 LA=1
4070 910 RETURN
4080 END
4090 SUBROUTINE BCOEF(LINO,LB,AB,ZB)
4100 DIMENSION AB(10)
4110 AB(LB)=ZB
4120 LB=LB+1
4130 IF(LB.LE.4) GO TO 920
4140 WRITE(11,15)LINO,(AB(LZ),LZ=1,4)
4150 LINO=LINO+10
4160 15 FORMAT(I5,1X,4(F9.4,1X))
4170 LB=1
4180 920 RETURN
4190 END
4200 SUBROUTINE CSTRANT(LINO,LC,AC,AD,AE,ZC,ZD,ZE)
4210 DIMENSION AC(4),AD(4),AE(4)
4220 AC(LC)=ZC
4230 AD(LC)=ZD
4240 AE(LC)=ZE
4250 LC=LC+1
4260 IF(LC.LE.4) GO TO 930
4270 WRITE(11,35)LINO,(AC(LZ),AD(LZ),AE(LZ),LZ=1,4)
4280 LINO=LINO+10
4290 35 FORMAT(I5,1X,4(2(I3,1X)F10.3,1X))
4300 LC=1
4310 930 RETURN
4320 END
```

Figure 14 (continued)

These instructions assume that the two FORTRAN programs, distance and solution data matrix generators, have been input to the users file.

1. DISTANCE MATRIX GENERATOR:

SYSTEM? FORT OLD DIS[1]
(insure that dimension statement corresponds to correct # nodes)

*RUN
= Input air statute and surface road miles for the feeder route nodes in the following order:

i \ j	1	2	3	4
1	-	1	2	3
2	-	-	4	5
3	-	-	-	6
4	-	-	-	-

(Air Miles)

i \ j	1	2	3	4
1	-	7	8	9
2	-	-	10	11
3	-	-	-	12
4	-	-	-	-

(Surface Miles)

2. Solution Data Matrix Generator

SYSTEM? FORT OLD MATEST[2]
(Insure that dimension statements are correct and that Call Attach files correspond to those in Distance Matrix generator program)

*RUN
= Input data in the order requested. When all inputs have been made, the program will print the variables, cross-reference numbers of variables, time coefficients

---

[1]DIS was the file name used in this research for the FORTRAN distance matrix generator program.

[2]MATEST was the file name used for the data matrix generator for test problem solution.

Figure 15

Instructions for Using FORTRAN Programs

and cost coefficients. The solution data matrix will be saved to the Call Attach file LOG5R.

```
*DONE
SYSTEM? FORT OLD LOG5R
```

Check and correct following:

(A) LINE 1ØØØ FOR CORRECT # VARIABLES, CONSTRAINTS, ETC.
(B) MIN VISIT "B" COEFF FOR RETURNING TO ALC FROM 1.Ø TO 6.Ø AND COEFF FOR BASE #6 FROM 1.Ø TO 3.Ø (OR MORE) IF TP3 DEMANDS ARE INCLUDED IN WT & VOL DEMANDS
(C) EXISTING BOTTOM LINE...CHECK FOR A COMPLETE GROUPING OF FOUR; IF NOT, COMPLETE LINE WITH Ø Ø Ø. Ø Ø Ø. UP TO FOUR
(D) LAST LINE SHOULD BE INSERTED AS A GROUPING OF FOUR ZERO GROUPS AS FOLLOWS: 329Ø Ø Ø Ø. Ø Ø Ø. Ø Ø Ø. Ø Ø Ø.

```
*DONE
```

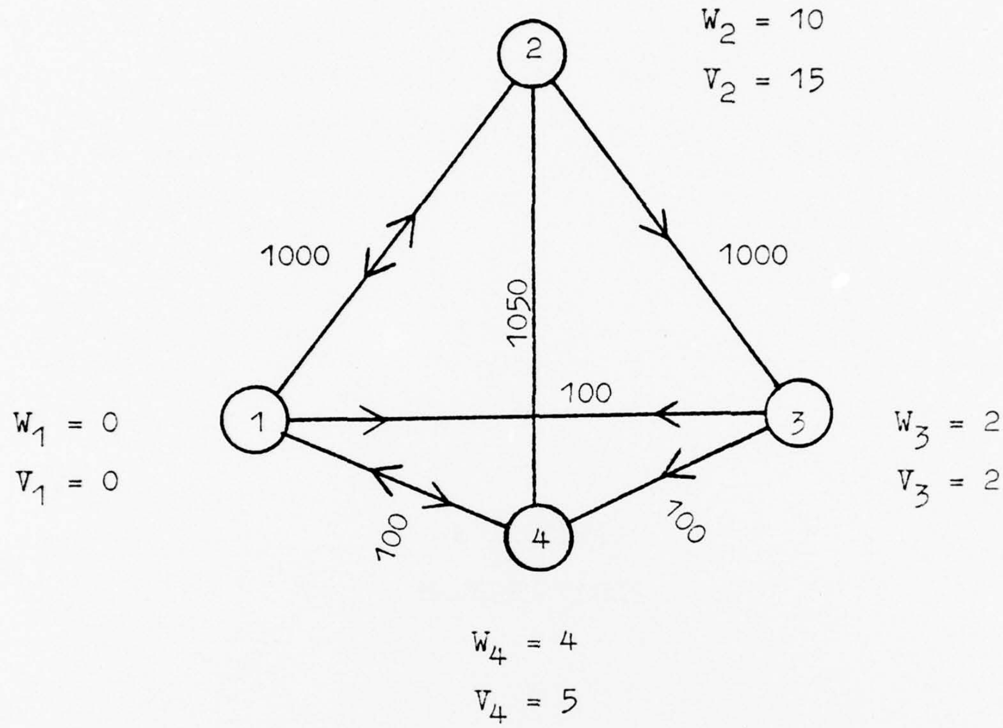
3. <u>RIP30C Solutions</u>

```
SYSTEM? CARD
OLD OR NEW - OLD AFIT.LIB/RIPRUN,R
READY
*10$:IDENT:
*65$:LIMITS:15,62K,4K . . . (OR UP TO LIMITS NECESSARY)
*100$:SELECTA: LOG5R
*RUN
```

Figure 15 (continued)

APPENDIX B

PILOT PROBLEM



W_j, V_j = daily weight and volume requirements for each node in tons and hundreds of cubic feet, respectively

Distance Unit = Miles

Figure 16

Pilot Problem

```
SYSTEM ?FORT OLD DIST
READY
*RUN
HAVE YOU CHANGED DIMENSION TO DISAIR(NN), DISGND(NN)?
=1ØØØ
=1ØØ
=1ØØ
=1ØØØ
=1Ø5Ø
=1ØØ
=1ØØØ
=1ØØ
=1ØØ
=1ØØØ
=1Ø5Ø
=1ØØ


DISTANCE MATRIX GENERATED IS:


********************************
     (I TO J) AIR DISTANCE
********************************

    Ø.      1ØØØ.ØØ    1ØØ.ØØ     1ØØ.ØØ
 1ØØØ.ØØ      Ø.      1ØØØ.ØØ    1Ø5Ø.ØØ
  1ØØ.ØØ   1ØØØ.ØØ      Ø.        1ØØ.ØØ
  1ØØ.ØØ   1Ø5Ø.ØØ    1ØØ.ØØ       Ø.
********************************
    (I TO J) SURFACE DISTANCE
********************************

    Ø.      1ØØØ.ØØ    1ØØ.ØØ     1ØØ.ØØ
 1ØØØ.ØØ      Ø.      1ØØØ.ØØ    1Ø5Ø.ØØ
  1ØØ.ØØ   1ØØØ.ØØ      Ø.        1ØØ.ØØ
  1ØØ.ØØ   1Ø5Ø.ØØ    1ØØ.ØØ       Ø.

*
```

Figure 17

Data Input for Pilot Problem

```
SYSTEM ?FORT OLD MATEST

READY
*RUN

ENTER TOTAL NODES(# BASES + ALC)=INTEGER(N)
=4

ENTER TOTAL # VEHICLES=INTEGER(M)
=2

ENTER # VARIABLES IN INITIAL PARTIAL SOLUTION=OPTION 1
=Ø

ENTER = Ø,IF NO IMBEDDED LP; 1,IF OTHERWISE
=Ø

ENTER = Ø,IF COEFF SIGNS NORMAL; 1,IF SIGNS REVERSED
=Ø

ENTER = Ø,FOR INTERMEDIATE OUTPUT TO APPEAR; 1,IF OTHERWISE
=Ø

ENTER = Ø,IF COST COEFF ALL INTEGER; 1, IF OTHERWISE
=1

ENTER = Ø,OR OTHER AUGMENTATION RULE
=Ø

ENTER FREQUENCY OF INTERMEDIATE OUTPUT = INTEGER
=2Ø

ENTER = Ø,OR UPPER BOUND IF KNOWN
=Ø

ENTER = Ø,OR MAX # SURROGATE CONSTRAINTS, IF KNOWN
=Ø

ENTER = Ø,OR FREQUENCY OF IMBEDDED LP
=Ø

ENTER MAX TIME IN SECONDS
=12Ø

ENTER THE NUMBER OF THIS PROBLEM RUN- LOGAIR__
=99
```

Figure 17 (continued)

```
DIMENSION STATEMENT LINENO 1420,1430,1440 MAY REQUIRE REVISION
IF SO, UTILIZE FOLLOWING GUIDE TO UPDATE DIMENSIONS:

CIJK(NNM), TIJK(NNM), WJ(N), VJ(N), TK(M), WK(M), VK(M),
DISAIR(NN), DISGND(NN), KX(NNM), RATE(M), COST(M),
BA(N),BB(N),BC(M),BD(N),AA...AF(4)
ENTER WEIGHT DEMANDS FOR BASES 1,2,...,J
=0,10,2,4

ENTER VOLUME DEMANDS FOR BASES 1,2,...,J
=0,15,2,5

ENTER VEHICLE WEIGHT CONSTRAINTS FOR VEHICLES 1,2,...,M
=17,21

ENTER VEHICLE VOLUME CONSTRAINTS FOR VEHICLES 1,2,...,M
=30,25

ENTER VEHICLE TIME CONSTRAINTS FOR VEHICLES 1,2,...,M
=12,24

ENTER VEHICLE SPEEDS, MILES/HR, IN ORDER VEHICLES 1,2,...,M
=500

=40

ENTER VEHICLE PER MILE COSTS IN ORDER OF VEHICLE 1,2,...,M
=3

=1
```

Figure 17 (continued)

IJK SUBSCRIPT #	VARIABLE INDEX #	TIME(TIJK)	COST(CIJK)
1 2 1	1	3.00	3250.00
1 3 1	2	1.20	550.00
1 4 1	3	1.20	550.00
2 3 1	4	3.00	3250.00
2 4 1	5	3.10	3400.00
3 4 1	6	1.20	550.00
2 1 1	7	3.00	3250.00
3 1 1	8	1.20	550.00
4 1 1	9	1.20	550.00
1 2 2	10	23.00	1000.00
1 3 2	11	5.50	100.00
1 4 2	12	5.50	100.00
2 3 2	13	23.00	1000.00
2 4 2	14	29.25	1050.00
3 4 2	15	5.50	100.00
2 1 2	16	23.00	1000.00
3 1 2	17	5.50	100.00
4 1 2	18	5.50	100.00

*

Figure 17 (continued)

```
1000 28 13 0 0 20 0 0 0 0 120 0 1 0 LOGAIR99
1010 3250.0000   550.0000   550.0000 3250.0000
1020 3400.0000   550.0000  3250.0000  550.0000
1030  550.0000  1000.0000   100.0000  100.0000
1040 1000.0000  1050.0000   100.0000 1000.0000
1050  100.0000   100.0000
1060   12.0000    24.0000    -1.0000   -1.0000
1070   -1.0000    -1.0000     6.0000    1.0000
1080    1.0000     1.0000    0.         0.
1090   17.0000    21.0000    30.0000   25.0000
1100   0.         0.         0.         0.
1110   0.         0.         0.         0.
1120   0.         0.         0.         0.
1130  1  1    -3.000   1  2    -1.200   1  3    -1.200   1  4    -3.000
1140  1  5    -3.100   1  6    -1.200   1  7    -3.000   1  8    -1.200
1150  1  9    -1.200   2 10   -28.000   2 11    -5.500   2 12    -5.500
1160  2 13   -28.000   2 14   -29.250   2 15    -5.500   2 16   -23.000
1170  2 17    -5.500   2 18    -5.500   3  7     1.000   3 16     1.000
1180  3  8     1.000   3 17     1.000   3  9     1.000   3 18     1.000
1190  4  1     1.000   4 10     1.000   5  2     1.000   5 11     1.000
1200  5  4     1.000   5 13     1.000   6  3     1.000   6 12     1.000
1210  6  5     1.000   6 14     1.000   6  6     1.000   6 15     1.000
1220  7  7    -1.000   7 16    -1.000   7  8    -1.000   7 17    -1.000
1230  7  9    -1.000   7 18    -1.000   8  1    -1.000   8 10    -1.000
1240  9  2    -1.000   9 11    -1.000   9  4    -1.000   9 13    -1.000
1250 10  3    -1.000  10 12    -1.000  10  5    -1.000  10 14    -1.000
1260 10  6    -1.000  10 15    -1.000  11  1    -1.000  11  2    -1.000
1270 11  3    -1.000  11  4    -1.000  11  5    -1.000  11  6    -1.000
1280 11  7   999.000  11  8   999.000  11  9   999.000  12 10    -1.000
1290 12 11    -1.000  12 12    -1.000  12 13    -1.000  12 14    -1.000
1300 12 15    -1.000  12 16   999.000  12 17   999.000  12 18   999.000
1310 13  1   -10.000  13  2    -2.000  13  3    -4.000  13  4    -2.000
1320 13  5    -4.000  13  6    -4.000  13  7    0.      13  8    0.
1330 13  9    0.      14 10   -10.000  14 11    -2.000  14 12    -4.000
1340 14 13    -2.000  14 14    -4.000  14 15    -4.000  14 16    0.
1350 14 17    0.      14 18    0.      15  1   -15.000  15  2    -2.000
1360 15  3    -5.000  15  4    -2.000  15  5    -5.000  15  6    -5.000
1370 15  7    0.      15  8    0.      15  9    0.      16 10   -15.000
1380 16 11    -2.000  16 12    -5.000  16 13    -2.000  16 14    -5.000
1390 16 15    -5.000  16 16    0.      16 17    0.      16 18    0.
1400 17  1     1.000  17  4    -1.000  17  5    -1.000  17  7    -1.000
1410 18  2     1.000  18  4     1.000  18  6    -1.000  18  8    -1.000
1420 19  3     1.000  19  5     1.000  19  6     1.000  19  9    -1.000
1430 20 10     1.000  20 13    -1.000  20 14    -1.000  20 16    -1.000
1440 21 11     1.000  21 13     1.000  21 15    -1.000  21 17    -1.000
1450 22 12     1.000  22 14     1.000  22 15     1.000  22 18    -1.000
1460 23  1    -1.000  23  4     1.000  23  5     1.000  23  7     1.000
1470 24  2    -1.000  24  4    -1.000  24  6     1.000  24  8     1.000
1480 25  3    -1.000  25  5    -1.000  25  6    -1.000  25  9     1.000
1490 26 10    -1.000  26 13     1.000  26 14     1.000  26 16     1.000
1500 27 11    -1.000  27 13    -1.000  27 15     1.000  27 17     1.000
1510 28 12    -1.000  28 14    -1.000  28 15    -1.000  28 18     1.000
1520 0 0 0. 0 0 0. 0 0 0. 0 0 0.
```


Figure 17 (continued)

Table 3

Pilot Problem Data Base

Vehicle	Capacity W_k (Tons)	Capacity V_k (100 Cu Ft)	Cost Per Mile ($)	Average Speed (MPH)	Load/Unload Time Per Leg (Hr)	Pipeline Time Restriction T_k (hr)
1 (Air)	7	12	3	500	1	12
2 (Surface)	7	12	1	40	3	24

Table 4

Pilot Problem Solution

Possible Solutions	Aircraft	Truck
1-2-3-4-1	7600	*
1-2-3-1	7050	*
1-2-1	**6500	*
1-2-4-1	7200	*
1-4-1	1100	200
1-3-4-1	1650	**300
1-3-1	1100	200

*Not feasible because of time

**Optimal combination of aircraft and truck

Table 5

Pilot Problem Formulation
(Basic Model)

Let: X_{ijk} = 1, if from station i to station j via vehicle k 0, if not

t_{ijk} = pipeline time, including onload/offload, from station i to station j via vehicle k

w_j = daily weight demand at station j

v_j = daily volume demand at station j

T_k = maximum pipeline time via vehicle k

W_k = maximum weight capacity vehicle k

V_k = maximum volume capacity vehicle k

Objective function:

Minimize:

$$3250X_{121} + 550X_{131} + 550X_{141} + 3250X_{231} + 3400X_{241} + 550X_{341} + 3250X_{211} + 550X_{311} + 550X_{411} + 1000X_{122} + 100X_{132} + 100X_{142} + 1000X_{232} + 1050X_{242} + 100X_{342} + 1000X_{212} + 100X_{312} + 100X_{412}$$

Subject to:

Time Constraints

$$3.00X_{121} + 1.20X_{131} + 1.20X_{141} + 3.00X_{231} + 3.10X_{241} + 1.20X_{341} + 3.00X_{211} + 1.20X_{311} + 1.20X_{411} \leq 12$$

Table 5 (continued)

$$28.00X_{122} + 5.50X_{132} + 5.50X_{142} +$$
$$2800X_{232} + 29.25X_{242} + 5.50X_{342} +$$
$$28.00X_{212} + 5.50X_{312} + 5.50X_{412} \leq 24$$

MIN VISIT CONSTRAINTS

$$X_{121} + X_{122} = 1$$
$$X_{131} + X_{231} + X_{132} + X_{232} = 1$$
$$X_{141} + X_{241} + X_{341} + X_{142} + X_{242} +$$
$$X_{342} = 1$$
$$X_{211} + X_{311} + X_{411} + X_{212} + X_{312} +$$
$$X_{412} \geq 1 \leq 6$$

OUT AND BACK CONSTRAINTS

$$X_{121} + X_{131} + X_{141} + X_{231} + X_{341} +$$
$$X_{241} + X_{211} + X_{311} + X_{411} \leq$$
$$999\ (X_{211} + X_{311} + X_{411})$$

$$X_{122} + X_{132} + X_{142} + X_{232} + X_{342} +$$
$$X_{242} + X_{212} + X_{312} + X_{412} \leq$$
$$999\ (X_{212} + X_{312} + X_{412})$$

BALANCE CONSTRAINTS

$$X_{121} = X_{231} + X_{241} + X_{211}$$
$$X_{131} + X_{231} = X_{311} + X_{341}$$
$$X_{141} + X_{241} + X_{341} = X_{411}$$

Table 5 (continued)

$$X_{122} = X_{232} + X_{242} + X_{212}$$

$$X_{132} + X_{232} = X_{312} + X_{342}$$

$$X_{142} + X_{242} + X_{342} = X_{411}$$

CAPACITY CONSTRAINTS

$$10X_{121} + 2X_{131} + 4X_{141} + 2X_{231} + 4X_{341} + 4X_{241} \leq 17$$

$$10X_{122} + 2X_{132} + 4X_{142} + 2X_{232} + 4X_{342} + 4X_{242} \leq 21$$

$$15X_{121} + 2X_{131} + 5X_{141} + 2X_{231} + 5X_{341} + 5X_{241} \leq 30$$

$$15X_{122} + 2X_{132} + 5X_{142} + 2X_{232} + 5X_{342} + 5X_{242} \leq 25$$

Table 6

Pilot Problem Formulation
(Transformed)

Minimize:

$$3250X_{121} + 550X_{131} + 550X_{141} + 3250X_{231} +$$
$$3400X_{241} + 550X_{341} + 3250X_{211} + 550X_{311} +$$
$$550X_{411} + 1000X_{122} + 100X_{132} + 100X_{142} +$$
$$1000X_{232} + 1050X_{242} + 100X_{342} + 1000X_{212} +$$
$$100X_{312} + 100X_{412}$$

Subject to:

$$-3.00X_{121} - 1.20X_{131} - 1.20X_{141} - 3.00X_{231}$$
$$-3.10X_{241} - 1.20X_{341} - 3.00X_{211} - 1.20X_{311}$$
$$-1.20X + 12 \geq 0$$

$$-28.00X_{122} - 5.50X_{132} - 5.50X_{142}$$
$$-28.00X_{232} - 29.25X_{242} - 5.50X_{342}$$
$$-28.00X_{212} - 5.50X_{312} - 5.50X_{412} + 24 \geq 0$$

$$X_{121} + X_{122} - 1 \geq 0$$
$$-X_{121} - X_{122} + 1 \geq 0$$
$$X_{131} + X_{231} + X_{132} + X_{232} - 1 \geq 0$$
$$-X_{131} - X_{231} - X_{132} - X_{232} + 1 \geq 0$$
$$X_{141} + X_{241} + X_{341} + X_{142} + X_{242} +$$
$$X_{342} - 1 \geq 0$$

Table 6 (continued)

$$-X_{141} - X_{241} - X_{341} - X_{142} - X_{242} - X_{342} + 1 \geq 0$$

$$+X_{211} + X_{311} + X_{411} + X_{212} + X_{312} + X_{412} - 1 \geq 0$$

$$-X_{211} - X_{311} - X_{411} - X_{212} - X_{312} - X_{412} + 6 \geq 0$$

$$-X_{121} - X_{131} - X_{141} - X_{231} - X_{341} - X_{241} - X_{211} - X_{311} - X_{411} + 999X_{211} + 999X_{311} + 999X_{411} \geq 0$$

$$-X_{122} - X_{132} - X_{142} - X_{232} - X_{342} - X_{242} - X_{212} - X_{312} - X_{412} + 999X_{212} + 999X_{312} + 999X_{412} \geq 0$$

$$X_{121} - X_{231} - X_{241} - X_{211} \geq 0$$

$$-X_{121} + X_{231} + X_{241} + X_{211} \geq 0$$

$$X_{131} + X_{231} - X_{311} - X_{341} \geq 0$$

$$-X_{131} - X_{231} + X_{311} + X_{341} \geq 0$$

$$X_{141} + X_{241} + X_{341} - X_{411} \geq 0$$

$$-X_{141} - X_{241} - X_{341} + X_{411} \geq 0$$

$$X_{133} - X_{232} - X_{242} - X_{212} \geq 0$$

$$-X_{122} + X_{232} + X_{242} + X_{212} \geq 0$$

Table 6 (continued)

$$X_{132} + X_{232} - X_{312} - X_{342} \geq 0$$
$$-X_{132} - X_{232} + X_{312} + X_{342} \geq 0$$

$$X_{142} + X_{242} + X_{342} - X_{411} \geq 0$$
$$-X_{142} - X_{242} - X_{342} + X_{411} \geq 0$$

$$-10X_{121} - 2X_{131} - 4X_{141} - 2X_{231}$$
$$-4X_{341} - 4X_{241} + 17 \geq 0$$

$$-10X_{122} - 2X_{132} - 4X_{142} - 2X_{232}$$
$$-4X_{342} - 4X_{242} + 21 \geq 0$$

$$-15X_{121} - 2X_{131} - 5X_{141} - 2X_{231}$$
$$-5X_{341} - 5X_{241} + 30 \geq 0$$

$$-15X_{122} - 2X_{132} - 5X_{142} - 2X_{232}$$
$$-5X_{342} - 5X_{242} + 25 \geq 0$$

Table 7

Pilot Problem Solution

LOGTEST

```
IMPLICIT ENUMERATION COMPLETE      TOTAL TIME=5173.594

LEAST Z BEFORE VARIABLE CHANGE = 6.80000000E 03

1   0   0   0   0   0   7   0   0   0   11   0   0   0   15

0   0   18

NO. FEASIBLE SOLUTIONS      4
ZS GE ZBAR      0 TIMES
CONSTRAINT INFEASIBLE      5 TIMES
AUGMENTATION IMPOSSIBLE      0 TIMES
AUGMENTATION POSSIBLE      8 TIMES
INTEGER DUALS      0 TIMES
NO. OF ROUNDED INT. DUALS      0
LP FATHOMED      0 TIMES
LP CALLED      0 TIMES
NO. ITERATIONS      17
LAST FEASIBLE SOLUTION    AT8813.875    SECONDS
```

APPENDIX C

LOGAIR PROBLEM SUPPORT DATA

Table 8

Daily Demands: Feeder Route 5R

Feeder Bases / Offline Support Bases[1]	Priority 1 & 2 Tons	Priority 1 & 2 Cu Ft	Priority 3 Big Cargo Tons	Priority 3 Big Cargo Cu Ft	Priority 3 Small Cargo[2] Tons	Priority 3 Small Cargo[2] Cu Ft
Barksdale AFB LA (BAD)	1.20	215	.49	101	.19	78
Doyline LA	*[3]	*	*	*	*	*
Marshall TX	*	*	*	*	*	*
Red River Arsenal TX	.02	3	*	*	.01	1
BAD Daily Demand	1.22	218	.49	101	.20	79
Blytheville AR (BYH)	.60	97	.22	50	.09	26
Defense Depot & NAS Memphis TN	.17	30	.07	8	.01	2
Ft Campbell KY	.02	3	*	*	.01	2
Millington TN	.01	1	*	*	*	1
BYH Daily Demand	.80	131	.29	58	.11	31
Eglin AFB FL (VPS) (including Crestview, Ft Walton, Milton & NAS Pensacola FL)	1.70	1046	.49	94	.29	112
Brewton AL	*	*	*	*	*	*
Fairhope AL	*	*	*	*	*	*
VPS Daily Demand	1.70	1046	.49	94	.29	112

Table 8 (continued)

Feeder Bases Offline Support Bases[1]	Priority 1 & 2 Tons	Priority 1 & 2 Cu Ft	Priority 3 Big Cargo Tons	Priority 3 Big Cargo Cu Ft	Priority 3 Small Cargo[2] Tons	Priority 3 Small Cargo[2] Cu Ft
England AFB LA (AEX)	1.03	202	.11	29	.04	30
Berwick & Houma AFS LA	*	*	*	*	*	*
Ft Polk LA	*	*	*	*	*	*
Lake Charles LA	*	*	*	*	*	*
AEX Daily Demand	1.03	202	.11	29	.04	30
Keesler AFB MS (BIX) (including Bay St Louis, Pascagoula & Gulfport MS)	.31	53	.17	30	.07	17
Belle Chasse LA	*	*	2.74	2163	1.80	1250
Camp Shelby MS	*	*	*	*	*	*
Dauphin Is AFS AL	*	*	*	*	*	*
Hammond & Slidell LA	*	*	*	*	*	*
ANG & NAS New Orleans LA	.16	30	.08	16	.04	9
Mobile AL	.20	29	*	*	*	*
BIX Daily Demand	.67	112	2.99	2209	1.91	1231

Table 8 (continued)

Feeder Bases	Priority 1 & 2		Priority 3			
			Big Cargo		Small Cargo[2]	
Offline Support Bases[1]	Tons	Cu Ft	Tons	Cu Ft	Tons	Cu Ft
Little Rock AFB AR (LRF) (including Little Rock AR)	1.07	184	.52	110	.21	62
N. Little Rock AR	*	*	*	*	*	*
Pine Bluff Arsenal AR	*	*	*	*	*	*
LRF Daily Demand	1.07	184	.52	110	.21	62

[1]Offline location requirements are supported through the feeder bases; total daily requirements at each feeder base include these outlying demands.

[2]Base requirements data are categorized by transportation categories "big" and "small". "Big" cargo is defined as that cargo which is too large for United Parcel Service, parcel post, etc., "small" cargo is that which can be shipped by these modes (7).

[3]Average daily demands less than .005 tons or .5 cubic feet are indicated by *.

(SOURCE OF DATA: DoD MATERIAL DISTRIBUTION SYSTEM STUDY GROUP (DODMDS), Courtesy of AFLC/XRS (16).

Table 9

Daily Requirements:[1] Feeder Route 5Q

Feeder Bases[2]	Priority 1 & 2 Tons	Priority 1 & 2 Cu Ft
Tyndall AFB FL (PAM)	1.16	200
MacDill AFB FL (MCF)	1.06	175
Patrick AFB FL (COF)	.21	37
Homestead AFB FL (HST)	1.43	310
Key West NAS FL (NQX)	.33	66
Jacksonville NAS FL (NIP)	.46	128
Moody AFB GA (VAD)	.14	20

[1]Priority 3 cargo not considered for Feeder Route 5Q

[2]All Offline Support Bases not considered significant.

Table 10

Vehicle Performance Characteristics

Vehicle	Capacity[1] Tonnage	Capacity[1] Cubic Feet	Fuel Consumption (gal/mile)	Average Cruise[2]	Offload/Onload Time Per Leg[3] (hours)
Aircraft:					
L188	28.5	3040	2.4	400	1.0
L100	37.8	4090	2.6	326	1.0
DC9	34.3	3060	3.0	540	1.0
Truck:					
45LF Trailer	12.0	3100	N/R	40	3.0
40LF Trailer	9.0	2400	N/R	40	3.0
28LF Trailer/Van	6.0	1700	N/R	40	3.0
18LF Van	4.0	1100	N/R	40	3.0

[1] Capacity limits for aircraft were obtained from the LOGAIR routing guide, the limitations on trucks were obtained from the Wright-Patterson AFB Transportation Office (21).

[2] Average air cruise speeds were obtained from the LOGAIR routing guide (17). Average truck cruise speed is based on the AAA all-road estimate of 100 miles per two hours and 30 minutes. (SOURCE: AAA TRIPTIK, p. 902, 1976 ed.).

[3] Offload/Onload times are estimates based on interviews with AFLC Transportation Directorate managers (7;9) and a base Transportation Office representative (21).

Table 11

Aircraft Transportation Costs
(Per Mile)

Aircraft Type	Basic Cost (BC)	+	Est. Fuel Subsidy (FC)	+	Est. Tax (TX)	=	Total Cost (TC)
L100	$3.5260		$.1690		$.114329		3.809329
L188	2.4128		.1560		.068067		2.636867
DC-9	2.4128		.1950		.058242		2.666042

Summary Computations:

FC = Fuel Consumption x Fuel Subsidy Differential[1]

TX = (BC - fuel basis x fuel consumption) x Overseas Factor x Tax Rate[2]

---

[1] Fuel Consumption obtained from Table 10. The fuel subsidy differential of $.065 is the difference between current fuel costs and the LOGAIR contract fuel basis of $.368. The fuel basis was supplied by LOGAIR management along with current fuel cost of $.433 from the basis for the subsidy to the contractor (7).

[2] LOGAIR manager J. Henderson also provided the overseas factor and tax rate, in addition to the fuel basis referenced in note 1. The overseas factor is 11 percent; therefore, 89 percent of the carrier's net earnings, not including fuel subsidy, is taxed at 5 percent. This amount is reimbursed to the carrier per the contract.

Table 12

Truck Transportation Costs

Truck Type	Estimated Contract Per Mile Cost[2]
45LF Trailer	$1.30
40LF Trailer[1]	1.25
28LF Trailer/Van	1.05
18LF Van	.95

[1]Most common carrier vehicle utilized (9).

[2]Estimated contract per mile costs are based upon a review of existing USAF dedicated contract truck routes--all routes negotiated by MTMC. Round trip contracts which were reviewed included: (1) Tinker AFB - Altus AFB, (2) McClellan AFB - Castle AFB, (3) NAS Dallas - Kelly AFB, (4) Tinker AFB - Kelly AFB - Dyess AFB, (5) Wright-Patterson AFB - Rickenbacker AFB, (6) Corpus Christi - Kelly AFB, and (7) NAS Dallas - Kelly AFB.

Table 13

Surface Statute Miles

i \ j	WRB	LRF	AEX	BIX	VPS	PAM	MCF	HST	NIP	BYH	BAD	NQX	COF	VAD
WRB	0	614	637	434	324	302	376	599	253	536	666	720	406	141
LRF	–	0	284	452	570	638	896	1146	812	174	233	1268	961	700
AEX	–	–	0	270	430	498	817	1068	744	424	117	1189	882	659
BIX	–	–	–	0	166	234	553	804	480	459	387	925	618	395
VPS	–	–	–	–	0	82	405	656	332	545	516	777	470	247
PAM	–	–	–	–	–	0	346	597	310	583	584	718	411	225
MCF	–	–	–	–	–	–	0	295	209	834	902	416	148	248
HST	–	–	–	–	–	–	–	0	386	1085	1153	124	241	471
NIP	–	–	–	–	–	–	–	–	0	750	818	507	166	136
BYH	–	–	–	–	–	–	–	–	–	0	407	1206	899	638
BAD	–	–	–	–	–	–	–	–	–	–	0	1274	967	706
NQX	–	–	–	–	–	–	–	–	–	–	–	0	362	592
COF	–	–	–	–	–	–	–	–	–	–	–	–	0	285
VAD	–	–	–	–	–	–	–	–	–	–	–	–	–	0

Table 14

Air Statute Miles

j / i	WRB	LRF	AEX	BIX	VPS	PAM	MCF	HST	NIP	BYH	BAD	NQX	COF	VAD
WRB	0	516	533	350	228	212	336	529	201	429	587	567	352	118
LRF	–	0	249	363	447	508	748	956	690	144	188	949	821	587
AEX	–	–	0	224	362	424	649	842	651	353	104	810	748	555
BIX	–	–	–	0	143	202	425	622	433	387	315	599	524	343
VPS	–	–	–	–	0	64	303	509	290	426	443	504	389	201
PAM	–	–	–	–	–	0	240	448	234	479	507	447	326	155
MCF	–	–	–	–	–	–	0	210	172	709	739	231	120	219
HST	–	–	–	–	–	–	–	0	336	918	937	103	190	414
NIP	–	–	–	–	–	–	–	–	0	621	725	390	152	104
BYH	–	–	–	–	–	–	–	–	–	0	320	926	763	520
BAD	–	–	–	–	–	–	–	–	–	–	0	909	832	625
NQX	–	–	–	–	–	–	–	–	–	–	–	0	261	450
COF	–	–	–	–	–	–	–	–	–	–	–	–	0	244
VAD	–	–	–	–	–	–	–	–	–	–	–	–	–	0

APPENDIX D

COMPUTER SOLUTIONS

Table 15

Feeder Route 5R Analysis--TP 1 and 2 Cargo

Vehicles[1] Considered	Solution: Optimum Vehicle/Routes	Support Time (Hours)[2]			Daily Cost of Optimum Route
		Vehicle #1	Vehicle #2	Vehicle #3	
DEFG	E/1-2-3-4-5-6-7-1	55.4			$2274.
AFFF	F/1-2-3-4-5-1	38.5			
	F/1-6-7-1		21.0		2752.
AEFG	F/1-4-5-6-7-1	42.5			
	G/1-2-3-1		23.8		2878.
AGGG	G/1-2-1	16.4			
	G/1-3-4-5-6-1		42.8		
	G/1-7-1			11.1	3218.
AEEE	E/1-2-3-4-5-1	38.5			
	E/1-6-7-1		21.0		3276.
DEFG	E/1-6-7-1	21.0			
	F/1-2-3-1		23.8		
	G/1-4-5-1			25.6	3895.
ABC	A/1-2-3-4-5-6-7-1	9.1			5600.

Table 16

Feeder Route 5R Analysis--TP 1, 2, and 3 Big Cargo

Vehicles Considered[1]	Solution: Optimum Vehicle/Routes	Support Time (Hours)[2]			Daily Cost of Optimum Route
		Vehicle #1	Vehicle #2	Vehicle #3	
DEFG	D/1-6-1	13.9			
	E/1-2-3-4-5-7-1		52.3		$3396.
ACDE	D/1-4-5-6-1	35.3			
	E/1-2-3-7-1		41.0		3938.
AEEE	E/1-2-3-4-5-1	38.5			
	E/1-6-1		13.9		
	E/1-7-1			11.1	4016.
ADDD	D/1-4-5-6-1	35.3			
	D/1-2-3-7-1		41.0		4018.
DEFG	D/1-5-6-1	28.7			
	F/1-4-7-1		35.5		
	G/1-2-3-1			23.8	4579.
ACDE	A/1-2-3-4-5-7-1	8.1			
	E/1-6-1		13.9		6422.
ADDD	A/1-2-3-4-5-7-1	8.1			
	D/1-6-1		13.9		6465.
ABC	A/1-2-3-4-5-7-1	8.1			
	C/1-6-1		1.7		7703.

Table 17

Feeder Route 5R Miscellaneous Analysis Delivery Every Other Day

Daily Cargo Demand	Vehicles Considered[1]	Solution: Optimum Vehicle/Route	Support Time (Hours)[2]			Optimum Cost	
			Vehicle #1	Vehicle #2	Vehicle #3	Route	Daily
TP1 & 2	A D EE	E/1-2-3-4-5-1 E/1-6-7-1	38.5	21.0		$3276.	$1638.
TP1 & 2	A D EE	A/1-2-3-4-5-1 E/1-6-7-1	4.7	21.0		6092.	3046.
TP1, 2, & 3 Big Cargo	A DD D EE	D/1-2-3-4-5-1 DD/1-6-1 EE/1-7-1	38.5	13.9	11.1	5273.	2637.
TP1, 2, & 3 Big Cargo	A DD D EE	A/1-2-3-4-5-1 DD/1-6-1 EE/1-7-1	4.7	13.9	11.1	8003.	4002.

Table 17A

Feeder Route 5R Miscellaneous Analysis Satisfying All

Demands--TP1, 2, and 3 All Cargo

Vehicles Considered[1]	Solution: Optimum Vehicle/Route	Support Time (Hours)[2]			Daily Cost of Optimum Route
		Vehicle #1	Vehicle #2	Vehicle #3	
A D EE F	A/1-2-3-4-5-7-1	8.1			
	EE/1-6-1		13.9		$7507.
A D EE F	D/1-2-3-4-5-1	38.5			
	EE/1-6-1		13.9		
	F/1-7-1			11.1	5057.

Table 18

Combined Feeder Routes 5R and 5Q TP 1 and 2 Cargo

Vehicles Considered[1]	Solution: Optimum Vehicle/Routes	Support Time (Hours)[2]			Daily Cost of Optimum Route
		Vehicle #1	Vehicle #2	Vehicle #3	
A,B,C	A/1-2-3-4-5-6-7-8-9-1	14.0			$8007
A,C,D	A/1-6-7-8-9-1	6.5			
	D/1-2-3-4-5-1		45.4		$6567
CDD	D/1-2-3-4-5-6-1	50.4			
	D/1-7-8-9-1		35.4		$3936

1. VEHICLE CODE:

Aircraft	Trucks
A. L188	D. 45LF
B. L100	E. 40LF
C. DC-9	F. 28LF
	G. 18LF

2. Support time (performance level), is the time to deliver to the last base on that vehicle's route, including unload time.

Table 19

RIP30C Program Limits (Basic Variables and

Constraints Vs Bases and Vehicles)

Number of Bases, N	Number of Vehicles, M													
	1		2		3		4		5		6		7	
	BV	CON	BV	CON	BV	CON	BV	CON	BV	CON	BV	CON	BV	CON
4	9	18	18	28	27	38	36	48	45	58	54	68	63	78
5	14	22	28	34	42	46	56	58	70	70	84	82	98	94
6	20	26	40	40	60	54	80	68	100	82	120	96	140	110
7	27	30	54	46	81	62	108	78	135	94	162	110	189	126
8	35	34	70	52	105	70	140	88	175	106	210	124	245	142
9	44	38	88	58	132	78	176	98	220	118	264	138	308	158
10	54	42	108	64	162	86	216	108	270	130	324	152	378	174
11	65	46	130	70	195	94	260	118	325	142	390	166	455	190
12	77	50	154	76	231	102	308	128	385	154	462	180	539	206
13	90	54	180	82	270	110	360	138	450	166	540	194	630	222
14	104	58	208	88	312	118	416	148	520	178	624	208	728	238

APPENDIX E

ANALYSIS SUMMARY

Table 20

Options Analysis Summary for 54 Variables and 46 Constraints

Iterations (10^3) 5 4 3 2 1 0	RIP30C Program Options	Time (hrs) 0 1 2 3 4 5
	None	
	LP Start	
	Imbedded LP, Freq. = 1	
	Imbedded LP, Freq. = 8	
	Imbedded LP, Freq. = 1 and Augmentation	
	Imbedded LP, Freq. = 8 and Augmentation	
	LP Start, Imbedded LP, Freq. = 1, and Augmentation	
	LP Start, Imbedded LP, Freq. = 8, and Augmentation	

Table 21

Options Analysis Summary for 81 Variables and 62 Constraints

Iterations (10^3) 5 4 3 2 1 0	RIP30C Program Options	Time (hrs) 0 1 2 3 4 5
	None	
	LP Start[1]	
	Imbedded LP, Freq. = 1	
	Imbedded LP, Freq. = 8	
	Imbedded LP, Freq. = 1 and Augmentation	
	Imbedded LP, Freq. = 8 and Augmentation	
	LP Start, Imbedded LP, Freq. = 1, and Augmentation	
	LP Start, Imbedded LP, Freq. = 8 and Augmentation	

[1] All other program options required only one iteration and 0.008 hours.

Table 22

Options Analysis Summary for 108 Variables and 78 Constraints

Iterations (10^3) 5 4 3 2 1 0	RIP30C Program Options	Time (hrs) 0 1 2 3 4 5
	None	
	LP Start[2]	
	Imbedded LP, Freq. = 1	
	Imbedded LP, Freq. = 8	
	Imbedded LP, Freq. = 1 and Augmentation	
	Imbedded LP, Freq. = 8 and Augmentation	
	LP Start, Imbedded LP, Freq. = 1, and Augmentation	
	LP Start Imbedded LP, Freq. = 8, and Augmentation	

[2]Solutions not possible with other options.

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